**INTRODUCTION**

Nanophase chemical elements are currently among the most promising constituents for the fabrication of nanocomposite systems, functional coatings, refractory compounds, catalysts, and sorbents [1–6].

There are a number of effective processes for the preparation of nanophase elements: destruction of substances in an electric discharge plasma using an electric arc, plasma generator radiation, glow discharge, and electroexplosion of wire; plasma synthesis; and others. The technology of ultrafine and nanosized powders has been the subject of extensive studies [1–10]. The loading of carbon matrices with solid particles of nanophase elements allows one to produce fundamentally new functional composite materials, control their properties, and impart special, unique characteristics associated with the macro- and microheterogeneity of the system and phase interactions at the matrix/filler interface [7, 10].

In selecting nanophase fillers and fabricating nanocomposite materials, the key characteristics are the specific surface area, the type of packing of filler particles, the distribution of the particles in the restraining matrix, the presence of functional groups on the surface of the material, and their reactivity.

In the fabrication of composite materials, the type of nanophase filler and its amount in a restraining matrix are typically selected empirically, with regard to the desired final properties and application areas of the material. The availability of a large number of fillers of various origins, with different particle sizes and physicochemical properties offers great possibilities to researchers for modifying composites and creating radically new materials with tailored properties [7–10].

Enormous experience has also been accumulated in producing energy-intensive anode materials. Among the world’s leading researchers in this field, mention should be given to the team of US and Swedish researchers who proposed a method for fabricating a three-dimensional anode for thin-film lithium ion (polymeric) batteries [11].

Chinese researchers developed a nanocomposite of carbon and \( \text{Co}_3\text{O}_4 \) nanoparticles. The use of this nanocomposite as an anode material in lithium ion (polymeric) batteries allows one to increase the specific electrical capacity and cyclability of the electrode, to extend its working temperature range, reduce its irreversible capacity, and improve its engineering performance [11].

Japanese researchers developed an efficient carbon–silicon anode composite, which possesses excellent processing and electrochemical properties (is capable of withstanding up to 2000 cycles) [11, 12].

Korean scientists created anode matrices based on copper oxide (CuO) nanostructures that enabled a 50% increase in the capacity of lithium ion (polymeric) batteries. They fabricated various nanostructures in which CuO molecules were arranged in the form of hexagons, spheres, and sea urchin-like structures. The last configuration proved the most efficient: the capacity of its graphite anode increased from 372 to 560 mA h [11, 12].

Japanese scientists investigated the structure of lithium iron silicon compounds (\( \text{FeO}_4 \) and \( \text{SiO}_4 \)) with the aim of employing them as anode materials for lithium...
the form of a hermetically sealed steel container. The grind- 
ing media in the high-energy vibratory mill were removed by washing with 10% HCl, analytical-grade acetone (RF State Standard GOST 2603-79), and distilled water. The finally dried powders were placed in the biological safety cabinet (AC3) and placed in glass flasks. Next, a HCl solution was added in small portions to remove MgO and other impurities. The mixtures were left to stand until complete precipitation of tungsten, molybdenum, silicon, and copper particles. Next, the solution was removed using a purpose-designed pumping device, and the particles were washed with distilled water and acetone.

The resultant thick pastes were dried using a purpose-designed vacuum drying oven (incorporated into the biological safety cabinet) until complete removal of the acetone. The finally dried powders were placed in the reservoir of an ultrasonic bath (incorporated into the biological safety cabinet) and sonicated to prevent particle agglomeration. Next, the powders were packed up and stored in hermetically sealed glass bottles.

**Characterization techniques.** The phase composition of the tungsten, molybdenum, silicon, and copper nanopowders was determined by X-ray diffraction on an Advanced D8 diffractometer (Germany) with CuKα radiation using a standard technique. The compounds present were identified in an EVA automatic mode using ICDD PDF-2 data.

The surface structure and the nanoparticle shape and size were determined using scanning electron microscopy (SEM) on an EVO-50XVP (Carl Zeiss, Germany) and an MT 8530 inverted metallurgical microscope (Meiji Techno, Japan) equipped with Thixomet PRO software.

The structure of the nanopowders was examined by atomic force microscopy (AFM) on a SOLVER-PRO (NT-MDT, Russia). The particle size distribution and size composition were determined using an Analysette

EXPERIMENTAL

**Preparation technique.** To prepare tungsten, molybdenum, silicon, and copper nanopowders and fabricate functional materials and composite systems from the powders, we used mechanochemical processing [7–17].

Nonphase elements (tungsten, molybdenum, silicon, and copper) were prepared from mechanically activated WO₃, MoO₃, SiO₂, and CuO with a specific surface area of ~190 m²/g and particle size of about 0.7 μm. In addition, we used MG-90 magnesium in the form of fine turnings. Impurities were removed by washing with 10% HCl, analytical-grade acetone (RF State Standard GOST 2603-79), and distilled water. WO₃ and SiO₂ were prepared from scheelite (CaWO₄) and thorny bamboo (Bambusa vulgaris), respectively, through mechanochemical processing and heat treatment [4–7, 13, 17–20]. MoO₃ and CuO were off-the-shelf.

WO₃, MoO₃, SiO₂, and CuO were reduced in a high-energy vibratory mill designed at the Far East State Technical University (FESTU) [17]. The grinding media in the high-energy vibratory mill were 14-mm-diameter VK-8 hard alloy balls. The mechanochemical reactor of the high-energy vibratory mill had the form of a hermetically sealed steel container (50-mm inner diameter, 125-mm height) with holes for gas delivery. The starting materials used were WO₃ (45.55 g), MoO₃ (20 g), SiO₂ (12.5 g), CuO (33.3 g), and magnesium (10 g in all reactions). The weight percentages of the components corresponded to the stoichiometry of the reduction of MoO₃, WO₃, SiO₂, and CuO with magnesium:

\[
\text{MoO}_3 + 3\text{Mg} = \text{Mo} + 3\text{MgO} \quad (1) \\
\text{WO}_3 + 3\text{Mg} = \text{W} + 3\text{MgO} \quad (2) \\
\text{SiO}_2 + 2\text{Mg} = \text{Si} + 2\text{MgO} \quad (3) \\
\text{CuO} + \text{Mg} = \text{Cu} + \text{MgO} \quad (4)
\]

The reduction of WO₃, MoO₃, SiO₂, and CuO in the high-energy vibratory mill was carried out under the following conditions: vibrational frequency of the reactor, 12 Hz; amplitude, 90 mm; atmosphere, argon; rate (powder-to-ball weight ratio), 1:20; filling of the mechanochemical reactor with the media, 30 vol%; total ball weight, 480 g. The synthesis duration was adjusted in experiments: 27 min for MoO₃, 21 min for WO₃, 37 min for SiO₂, and 17 min for CuO.

To avoid oxidation, the resultant powders were withdrawn from the reactor in a Class III biological safety cabinet (AC3) and placed in glass flasks. Next, a HCl solution was added in small portions to remove MgO and other impurities. The mixtures were left to stand until complete precipitation of tungsten, molybdenum, silicon, and copper particles. Next, the solution was removed using a purpose-designed pumping device, and the particles were washed with distilled water and acetone.

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