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SYNTHESIS OF Ni AND Cu NANOPOWDERS BY ELECTROLYSIS

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The preparation of ceramic composites based on metal nanopowders allows us to change significantly the thermal characteristics of the ceramic matrix, which is important for the creation of heat-conducting ceramics technology.

The work establishes the most efficient method of obtaining nickel nanopowder on a "P-5848" potentiostat by electrolysis of nickel sulfate ($NiSO_4$) with the addition of boric acid (H_3BO_3), thiourea ((NH_4)$_2CS$) and nickel(II) chloride ($NiCl_2$). The synthesis of Ni nanopowder was carried out at a current density from 1.0 to 3.3 A/dm^2 and at a temperature of 45–65 °C, where a platinum (Pt) plate was chosen as an anode, and the cathode was specially made of especially pure aluminum (Al). The results of the study showed the synthesis of Ni nanopowder with a size of 55 nm in the form of thin scales. Electrochemical reactions at the cathode and anode are also considered in the work.

Several successful experiments were also carried out in the work, which made it possible to develop an economically profitable technology for the synthesis of copper nanopowder by the electrolysis method at 13.3 ampere-hours of current per 1 dm^2 of the anode surface at a relatively low temperature of the copper sulfate solution ($CuSO_4$). Copper nanopowder is removed to the bottom of the bath from the anode by impact shaking. An equally successful experiment was carried out, where the cathode was in the form of several copper plates at the distance of 0.8 cm from each other with a voltage between them of 0.775 V, and a current density of 15.3 A/dm^2 at the temperature of 54 °C in an electrolyte with 45 % H_2SO_4, 8 % Na_2SO_4 and 4 % $CuSO_4$.

The work contains tables with initial and final data of all experiments on the synthesis of nanopowders by the electrolysis method.

Keywords: *copper (Cu) nanopowder, nickel (Ni) nanopowder, electrochemistry, dendritic copper, nickel (Ni) nanopowder, potentiostat, aluminum (Al) cathode, platinum (Pt) anode*

INTRODUCTION

Nanopowders of nickel and copper can be used in thermal physics to improve the thermal conductivity of materials. This is due to the fact that nanoparticles have a larger surface compared to larger particles, which allows them to transfer heat better.

For example, nickel nanopowders can be added to thermal insulation materials in order to improve their thermal conductivity and increase the efficiency of heat exchange. Also, copper nanopowders can be used to create heat-conducting materials coated on the surface.

The second application of nickel and copper nanopowders in thermophysics is their use as catalysts for reactions associated with the release of heat. For example, copper nanoparticles can be used as catalysts in the oxidation of ammonia, which leads to the release of heat.

Thus, the use of nanopowders of nickel and copper can lead to an improvement in the thermophysical properties of materials and an

increase in the efficiency of heat exchange, which can be useful in various fields, including energy, heat engineering, and catalysis.

The creation of cheap production of nanopowders of nickel (Ni) and copper (Cu) is an important task of the modern world, as preliminary results indicate that such powders can be the key to the synthesis of modern soluble (fullerenes [1–4], fullerites [4, 5], endofullerenes [6]) and insoluble carbon nanostructures (carbon nanotubes [2, 3, 7–18], graphene and their packages [2, 19]). From them it is possible to create modern composite materials [20–22] that can be filled with both micro [23–25] and nanofillers [26–34]. Such synthesized carbon nanostructures and composites based on them can be used in various industries: medicine and biology [35–39], solar energy [40–42], sorption materials [43–49], even in hydrogen energy as promising hydrogen sorbents [50–54], which are capable to compete with existing advanced materials for hydrogen storage [55–73].

Obtaining cheap nano-sized powder will make it possible to take a step in their use in the field of additive technologies: 3D printing of selective melting SLM (Selective laser melting), where pure nanopowders are used; in CJP (Color Jet Printing), where nanopowders are used as ceramic matrix fillers to create thermally conductive ceramics; as well as in the layer-by-layer deposition of thermoplastic materials using the FDM (Fused Deposition Modeling) technology, stereolithography SLA (Stereo lithography Apparatus), and selective laser sintering SLS (Selective Laser Sintering), where metal nanopowders are used as polymer matrix fillers to improve their characteristics. Already today, 3D printing allows you to create 3D products from a minimum amount of consumables, which makes products with a lower cost.

The successful use of nickel and copper nanopowders in various fields as catalysts depends on their pretreatment and preparation technology [6, 13, 16, 78–91]. As a rule, catalysts of three types are used: pure metals [92–95], metal alloys [96–98] and mechanical mixtures of metals or their alloys [99–101].

As is well known, nickel powders are now increasingly used, especially in radar devices and modern telephones [102–105].

As it for nickel powders of especially high dispersion, they are a much cheaper material than platinum and palladium, and they replace these metals as catalysts for hydrogenation processes in the technology of synthesis of a number of organic substances and nanostructured materials [106, 107]. However, today obtaining nanocrystalline powders using electrochemical methods is still significantly delayed.

Nevertheless, in the market of nanopowders of pure metals (copper (Cu) and nickel (Ni)), nickel powders take the leading position in a fairly large amount (~16.5 %). However, these powders are often not the end product, but are used in various intermediate production processes. Nanopowders of copper (Cu) and nickel (Ni) are already widely used in two key industries – electronics and processing industry. Thus, the volume of practical use of nickel nanopowders is constantly growing.

In addition to the above, copper and nickel nanopowders are characterized by a high value of magnetic saturation induction and are therefore a promising material for creating magnetic fluids and compact composite materials. Such ultra-dispersed powders can also be granulated, which also increases their technological value.

The high specific surface area of copper and nickel nanopowders allows its application in a number of chemical industries, primarily in electrochemistry. In particular, nickel anodes made of nanopowders are already used for nickel plating and copper plating of various products.

Another type of product made from nanopowder (nickel sheets) is currently used in electronic spectroscopy, mass spectrometry with induced plasma, low-temperature nitrogen adsorption, laser diffraction, as well as for dynamic light scattering. In addition, based on pure nickel nanopowders, porous filters are already being produced for gas purification from fuel and other chemical industry products.

It is also known that copper and nickel nanopowders are promising materials for creating magnetic fluids in recording and information storage systems, for creating permanent magnets as magnetic sensors, as well as in medicine: for targeted delivery of drugs, as well as magnetic resonance imaging.

In the field of materials science, nickel nanopowders have the prospect of wider use in obtaining nickel hydrides for batteries and

improving the cathode and anode materials of modern solid oxide fuel cells.

Recently, there has been a significant increase in interest in the industrial production of copper nanopowders, but attempts to obtain pure copper powder have been associated with certain difficulties. For example, in [108], a method for obtaining copper nanopowder in the presence of polyacrylate was presented, which affects the size (increased) and lack of necessary purity of the manufactured powder. The authors of the cited work were able to obtain only the boundary state of nanoscale size with a small purity of copper powder.

At the same time, E.S. Zotova [109] was able to obtain more finely dispersed copper nanoparticles with a size of 2 to 5 nanometers, which, however, represent metal cores with an oxide film on the surface, mixed with a fairly large amount of already less fine (~20 nm) particles of copper oxide CuO. Such material will require additional processing to obtain pure copper.

Similar difficulties (insufficiently pure copper) were also encountered by A.I. Gusev [110] and H.Yu. Symenyuk, I.I. Obrazova and N.K. Yeryomenko [111] when using copper nanopowder in catalysis and automotive industry.

Obtain exclusively pure nanocrystalline powders are obtained of nickel (Ni) and copper (Cu), which is important for their application not only in the aforementioned areas, but also in the electrical and radio-electronic industries, in the production of filters for fine oil purification, as well as in the production of metal-ceramic products, gaskets and bushings [112].

Therefore, the main task of this work is to obtain the maximum purity of nanopowders of metals copper (Cu) and nickel (Ni), and the electrochemical method of synthesis was chosen due to the low cost of such nanopowders.

EQUIPMENT USED IN EXPERIMENTAL STUDIES

During electrolysis, heat is generated. It heats up the environment and the installation. To dissipate the heat, the working vessel was submerged in a glass containing a mixture of ice and salt (Fig. 1), which made it possible to regulate the temperature of the electrolyte and maintain it within the range of 15 to 65 °C at an anodic current density of 1.0 to 3.3 A/dm^2.

Also, the temperature of the environment can be lowered by artificially interrupting the operation mode of the electrolysis installation, but this option is not considered as it excludes the possibility of using this method for industrial production of nickel and copper nanopowders. Thus, the design of the device allowed for maintaining the temperature at the desired level.
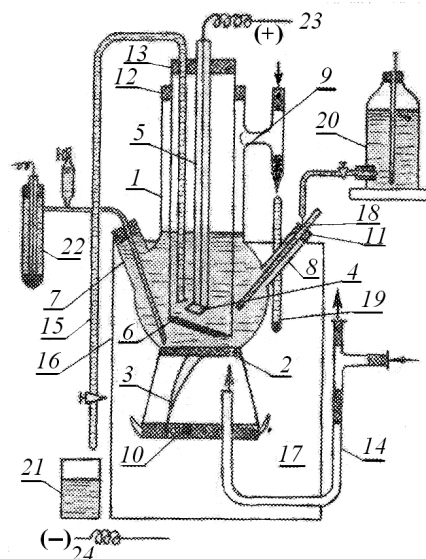

Fig. 1. The device scheme: *1* – glassware; *2* – cathode; *3* – current supply to the cathode; *4* – anode; *5* – current supply to the anode; *6* – diaphragm; *7–9* – tubes; *10–13* – rubber plugs; *14* – brass tube; *15* – siphon; *16* – external vessel; *17* – ice and salt; *18, 19* – thermometers; *20* – pressure vessel; *21* – a glass; *22* – reference electrode; *23, 24* – wires to a P-5848 potentiostat

The diagram explaining the principle of operation with a potentiostat is shown in Fig. 2. From the diagram, it can be seen that a voltage is applied to one input of the amplifier, and the potential difference between the "reference electrode" and the "working electrode" is applied to the other input. The input voltages in the amplifier are compared, and the resulting difference controls the output current of the amplifier, which polarizes the working electrode to the potential set on the voltage source.

The accuracy of maintaining the potential of the working electrode is determined by the stability of the amplifier and the amplification coefficient.

To increase the measurement and maintenance accuracy of the working electrode potential in the potentiostat, a four-wire

connection scheme of the electrochemical cell was used, in which the working electrode of the cell is grounded through a potential wire that does not carry the output current of the amplifier and, therefore, does not create a voltage drop on it. As a result, the potential of the working electrode relative to the reference electrode will almost exactly correspond to the given value. The value of the applied voltage, and therefore, the potential of the working electrode, can be changed in steps and according to a linear law. The polarization current value is measured by a milliammeter (mA). The potentiostat can also be used in a mode of maintaining the required polarization current value of the working electrode.

Cathodic potentials were mainly measured using a potentiometer P-5848 (Fig. 3). To prevent gas from entering, the reference electrode tip was inserted into a glass filter. Air was supplied to the electrode from an air pump and pumped out from the upper part of the vessel by a water jet pump. The pressure drop was measured by a mercury siphon manometer. The cathode potential measurements were carried out under the same conditions while maintaining a constant pH value.
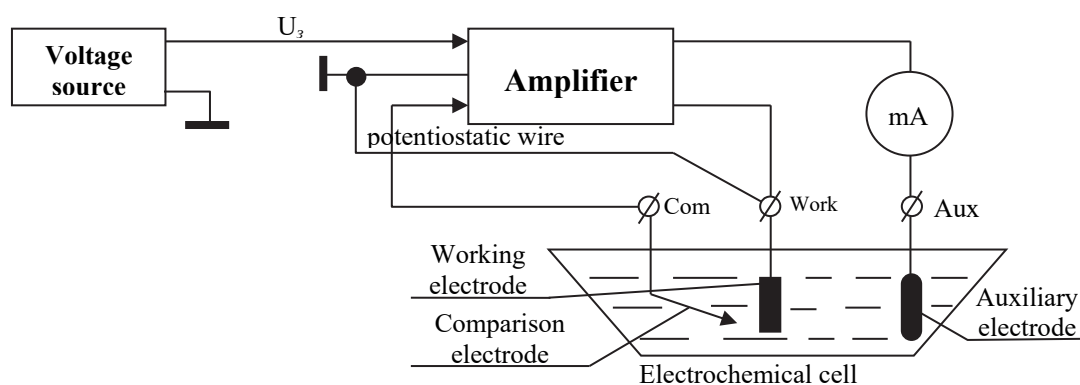

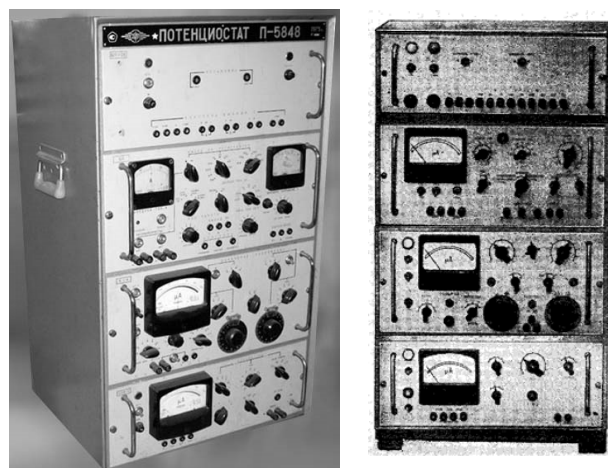**Fig. 2.** Scheme of the operation principle of a potentiostat P-5848

Fig. 3. Workstation of potentiostat P-5848

The potentiostat P-5848 used three amplifiers of different types: a main direct currentamplifier, an output power amplifier, and a direct current-stabilizing amplifier with signal conversion.

The potentiostat P-5848 also used three cascaded differential direct current amplifiers with symmetric input and output. During galvanostatic operation, the voltage from the current multiplier resistor is applied to one input, and the voltage from the potential "programmer" is applied to the other input. This allows the use of a grounded zero wire potential "programmer" and reduces alternating current background. An

electronic potential "programmer" with a square pulse generator was connected to the second input through special terminals for external expansion, which does not interfere with the normal operation of the potentiostat. The required IE polarization current value is provided by a transistor power amplifier.

Due to the need for polarization of the working electrode with IE currents of different directions without switching the potentiostat, the output amplifiers consist of two independent circuits (amplifier *a* and amplifier *b*), connected in such a way that the current flowing through the working electrode IE is the difference between the output currents of these circuits.

The P-5848 potentiostat model allows for:
a) maintaining a potential of the working electrode;
b) changing the potential of the working electrode in steps and linearly with different speeds;
c) maintaining a given polarization current of the working electrode;

d) changing the polarization current of the working electrode in steps and linearly with different speeds;
e) changing the potential or polarization current of the working electrode according to the voltage of an external generator;
f) measuring the potential of the working electrode and polarization current.

NANOPOWDER MANUFACTURING TECHNOLOGY

### *Production of nickel nanopowder (Ni):*

This section proposes electrochemical methods for obtaining nickel nanopowder. The most economically feasible method is experiment N 1 (Table 1), which involves electrolysis of a solution of nickel sulfate ($NiSO_4$) with the addition of nickel II chloride ($NiCl_2$), boric acid (H_3BO_3), and thiourea (($NH_2)_2CS$), using a high-purity aluminum cathode (Al) and platinum (Pt) anode at a temperature of 45–65 °C and a current density on the cathode from 1.0 to 3.3 A/dm^2. This method produced nanopowder with an average particle size of 55 nm.

Table 1. Electrolysis modes of the experiment N 1

Working solution	Nickel Sulfate ($NiSO_4$)
Additives	Nickel (II) chloride ($NiCl_2$), Boric acid (H_3BO_3), Thiourea (($NH_2)_2CS$)
Cathode	Aluminum (Al)
Anode	Platinum (Pt)
The environment temperature, °C	45–65
Current density at the cathode, A/dm^2	1.0–3.3
The size of the obtained particles of nickel (Ni) powder, nm	55

In addition to the described method, nickel nanopowder was also obtained using another method in experiment N 2 (Table 2), which involved electrolysis with soluble nickel (Ni) anodes according to the reaction $Ni = Ni^{2+} + 2e$ and an aluminum (Al) cathode. In this case, a solution of nickel sulfate ($NiSO_4$) at a concentration of approximately 60 g/l, aluminum chloride ($AlCl_3$) at 15 g/l, and ammonia (NH_3) at 137 g/l was used as the electrolyte. To facilitate the removal of the nickel nanopowder precipitate from the electrolyte, 1 % stearic acid ($C_{17}H_{35}COOH$) and a small amount of solidol were added. The average particle size of the

obtained powder was 60 nm. The reaction that occurred was:

on the cathode:
$$Ni^{2+} + 2e = Ni,$$

on the anode:
$$2H_2O = O_2\uparrow + 4H^+ + 4e.$$
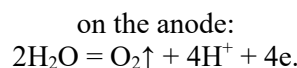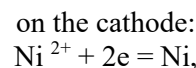
Through experimental methods, it has been found that the smallest nickel nanoparticles (~40 nm) can be obtained by using intermittent current during electrolysis. This means that the current was periodically interrupted during the electrolysis process.

It should be noted that during electrolysis, thiourea decomposes depending on its concentration, but the sulfur content in the obtained nickel powder varies only by 0.1–1.0 %, which practically does not affect the properties of nickel.

Table 2. Electrolysis modes of the experiment N 2

Working solution	Nickel sulfate ($NiSO_4$) – 60 g/l, Aluminum chloride ($AlCl_3$) – 15 g/l, Ammonia (NH_3) – 137 g/l
Additives	Nickel (II) chloride ($NiCl_2$), Boric acid (H_3BO_3), Thiourea ((NH_2)$_2$CS)
Cathode	Aluminum (Al)
Anode	Nickel (Ni)
The environment temperature, ºC	45–65
Current density at the cathode, A/dm^2	1.0–3.3
The size of the obtained particles of nickel (Ni) powder, nm	60
To remove the nanopowder, it was added to the electrolyte	Stearic acid ($C_{17}H_{35}COOH$) ~1 %, Solidol
By-products	Nitrogen (N) accumulates in the form of ammonia salt

Table 3. Electrolysis modes of the experiment N 3

Working solution	Nickel sulfate ($NiSO_4$) – 200–450 g/l, Nickel (II) chloride ($NiCl_2$) – 15–70 g/l, Boric acid (H_3BO_3) – 10-40 g/l
Additives	Thiourea ((NH_2)$_2$CS)
Cathode	Aluminum (Al)
Anode	Nickel (Ni)
The environment temperature, ºC	~15
Current density at the cathode, A/dm^2	1.0 to 3.3
The size of the obtained particles of nickel (Ni) powder, nm	70
To remove the nanopowder, it was added to the electrolyte	Stearic acid ($C_{17}H_{35}COOH$) ~1 %, Solidol
By-products	Nickel (II) hydroxide ($Ni(OH)_2$)

During electrolysis, nitrogen accumulates in the electrolytic bath in the form of ammonium salt, which should be removed from the solution by periodically crystallizing it during the cooling of the electrolytic bath.

However, it should be noted that in another variant of electrolysis (at lower temperatures – below 15 °C), the presence of a deposited salt on the cathode surface led to unwanted formation of nickel hydroxide $Ni(OH)_2$ nano-deposits in the form of flakes on a portion of the cathode surface. At the same time, in electrolysis of a solution containing 200–450 g/l nickel sulfate, 15–70 g/l nickel (II) chloride, and 10–40 g/l boric acid, it is possible to obtain nickel nanopowder in experiment N 3 (Table 3), although with a slightly larger average particle size (70 nm).

The obtained results indicate that the production of nickel nanopowder with different dispersion can be carried out under different conditions. We are confident that there is a more economical method for creating nickel nanopowder, which lies in yet unexplored potential variants of cathodic electrochemistry.

Production of copper (Cu) nanopowders:

In this work, dendritic-shaped and highly dispersed copper (Cu) nanopowders were obtained in experiment N 4 (Table 4). This result was achieved by regulating the process of synthesis of copper nanopowder with a bulk

density of 0.4 g/cm^3. Electrolysis of a low copper content electrolyte solution with a significant amount of sulfuric acid (H_2SO_4) was conducted at a high cathodic current density and relatively low temperature (~23 °C). Copper sulfate solution was used as the electrolyte, and copper plates served as the anode and cathode.

Table 4. Electrolysis modes of the experiment N 4

Working solution	Copper sulfate ($CuSO_4$)
Additives	Sulfuric acid (H_2SO_4)
Cathode	Copper (Cu)
Anode	Copper (Cu)
The environment temperature, °C	~23
Current density at the cathode, A/dm^2	1.0–3.3
The size of the obtained particles of copper (Cu) powder, nm	~40 (dendritic form)
To remove the Cu nanopowder	Periodic shaking or systematic blows to the electrodes
By-products	Absent

During the electrochemical synthesis of copper nanopowder, optimal concentrations of copper sulfate and sulfuric acid, as well as the ability to detail electrolysis conditions, play a significant role. The complexity of the copper nanopowder synthesis process is due to the prolonged growth of copper nanopowder, which requires periodic removal from the electrolyzer by shaking the cathode. At the same time, the copper cathode automatically falls to the bottom of the bath after approximately 13.3 ampere-hours of electrolysis (based on 1 dm^2 of the cathode).

In our case, the most optimal electrolysis process was found, in which copper nanopowder is systematically removed due to periodic shaking of the cathode. Such electrolysis conditions provide a sufficiently low level of electricity consumption while maintaining high production capacity of equipment. This regime can be scaled up and used for industrial production of crystalline copper nanopowder.

The next electrolysis regime conducted in experiment N 5 (Table 5) is also reasonable, where the cathode (copper plate) is placed 0.8 cm apart in an electrolyte containing 45 % sulfuric acid (H_2SO_4), 4 % copper sulfate ($CuSO_4$), and 8 % sodium sulfate (Na_2SO_4). The optimal electrolyte temperature is 54 °C, the current density on the cathode is 15.3 A/dm^2, and the voltage between the plates is 0.775 V.

Table 5. Electrolysis modes of the experiment N 5

Working solution	Copper sulfate ($CuSO_4$) – 4 % Sulfuric acid (H_2SO_4) – 45 % Sodium sulfate (Na_2SO_4) – 8 %
Cathode	Copper (Cu), placed at a distance 0.8 cm
Anode	Copper (Cu)
The environment temperature, °C	54
Current density at the cathode, A/dm^2	15.3
The voltage between the plates, V	0.775
The size of the obtained copper (Cu) powder particles, nm	>30 (dendritic form)
To remove copper (Cu) nanopowder	Periodic shaking or systematic blows on the cathode
By-products	Absent

It should be noted that adding finely ground, colloidal-like carbonized sugar or glucose treated with sulfuric acid to the above-mentioned electrolyte prevents possible hydrogen evolution at the cathode, thereby increasing the yield of copper nanopowder by current.

In some experiments, at higher current densities, the addition of sulfate glue or tannin to the electrolyte leads to an increase in the current density at the cathode and contributes to obtaining a more dispersed copper nanopowder, as well as prevents its possible oxidation.

In some cases, such scales are obtained a priori by pre-coating the cathodes with a layer of lubricants, such as paraffin or castor oil, and sometimes even corn oil.

The copper and nickel powders obtained in the form of scales after removal from the electrolysis bath are crushed in special "ball mills" or ground in a mortar to create uniformity. Previous studies have shown that such nanopowder can already be used in SLM 3D printing technology, or for creating new composites for FDM, SLA, CJP 3D printing.

CONCLUSIONS

In the work, an electrochemical cathodic synthesis of nickel (Ni) nanopowder with an average nanoparticle size of 55 nm was carried out, where nickel sulfate ($NiSO_4$) was used as an electrolyte with additives in the form of thiourea (($NH_2)_2CS$), nickel (II) chloride ($NiCl_2$) and boric acid (H_3BO_3). The two-hour electrolysis took place using a platinum (Pt) anode and a highly pure aluminum (Al) cathode at a temperature of 45–65 °C.

Copper (Cu) nanopowders with a particle size of up to 40 nm were also synthesized by electrolysis of mainly $CuSO_4$ with a high value of the cathode current density at almost room temperature (23 °C).

The main problem in the synthesis of copper nanopowder was the process of its removal from the synthesis zone. This issue was solved by the method of periodic impact on the electrode that fell to the bottom of the electrolytic bath after approximately 13 ampere-hours of electrolysis per 1 dm^2 of the cathode surface.

In this work, the following was also done:

1. It was experimentally found that thin nickel nanoparticles (~40 nm) can be obtained using pulsed current during electrolysis.

2. It was found that nitrogen accumulates in the electrolytic bath during the electrochemical synthesis of nickel nanopowder in the form of an ammonium salt, which should be removed by periodic crystallization during the cooling of the electrolytic bath.

3. The presence of solidol on the cathode surface in the electrolyte led to the undesirable formation of nickel hydroxide $Ni(OH)_2$ nanoscale deposits on a part of the cathode surface. The electrolysis temperature was > 15 °C.

4. The electrolysis process was found to be the most optimal, in which copper nanopowder is systematically removed due to periodic shaking of the cathode. These electrolysis conditions provide a sufficiently low level of energy consumption while maintaining high production equipment capacity.

5. It was found that adding finely ground, carbonized sugar or glucose treated with sulfuric acid during heating to the electrolyte prevents possible hydrogen evolution at the cathode, which in turn leads to increased copper nanopowder yield.

6. In some experiments with higher current density, adding gelatin glue or tannin to the electrolyte increases the current density on the cathode and promotes the formation of more dispersed copper nanopowder while preventing its possible oxidation.

7. Copper and nickel powders obtained in the form of flakes after removal from the electrolyzer bath can be crushed in special "ball mills" or ground in a mortar to create a homogeneous powder.

Also, preliminary analysis shows:

1. When using 3D printing of CJP (Color Jet Printing) technology, synthesized nanopowders can be used as ceramic matrix fillers to create heat-conducting ceramics with improved characteristics;

2. The obtained pure nanopowders of nickel and copper can be used in 3D printing of selective melting SLM (Selective laser melting), immediately after their synthesis;

3. Nanopowder can be used in 3D printing technology FDM (Fused Deposition Modeling) and SLA (Stereo lithography Apparatus) as polymer matrix fillers to improve their characteristics of 3D products;

4. The preliminary results indicate that nickel (Ni) and copper (Cu) nanopowders may

be the key to the synthesis of modern soluble and insoluble carbon nanomaterials.

The developed technology can be used for industrial production of crystalline copper and nickel nanopowders. In addition, the obtained results can be used in the production of modern iron-nickel (Fe-Ni) batteries.

Синтез нанопорошків Ni та Cu методом електролізу

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Приготування керамічних композитів на основі нанопорошків металу дозволяють значно змінити теплові характеристики керамічної матриці, що важливо для створення технології теплопровідної кераміки.

В роботі встановлений максимально ефективний спосіб отримання нанопорошку нікелю на потенціостаті «П-5848» електролізом сульфату нікелю ($NiSO_4$) з додаванням борної кислоти (H_3BO_3), тіосечовини (($NH_4)_2CS$) та хлориду нікелю (II) ($NiCl_2$). Синтез нанопорошку Ni проводився при густині струму від 1.0 до 3.3 А/дм^2 та при температурі 45–65 °C, де анодом була обрана платинова (Pt) пластина, а катод був спеціально виготовлений з особливо чистого алюмінію (Al). Результати дослідження показали синтез нанопорошку Ni при розмірі 55 нм у вигляді тонких лусок. В роботі також розглянуті електрохімічні реакції на катоді та на аноді.

Також в роботі проведено декілька вдалих експериментів, що дозволили встановити економічно вигідну технологію синтезу нанопорошку міді методом електролізу при 13.3 ампер-годин струму на 1 дм^2 площини аноду та при відносно низькій температурі розчину сульфату міді ($CuSO_4$). Мідний нанопорошок видаляється на дно ванни з аноду при ударному струшуванні. Не менш вдалий був проведений експеримент, де був катод у вигляді декількох мідних пластин на відстані 0.8 см одне від одного з напругою між ними в 0.775 В, та густиною струму 15.3 А/дм^2 при температурі 54 °C в електроліті з 45 % H_2SO_4, 8 % Na_2SO_4 і 4 % $CuSO_4$.

В роботі наведені таблиці з вихідними та кінцевими даними всіх експериментів з синтезу нанопорошків методом електролізу.

***Ключові слова**: нанопорошок міді (Cu), електрохімія, мідь дендритної форми, нанопорошок нікелю (Ni), потенціостат, алюмінієвий (Al) катод, платиновий (Pt) анод*

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