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INVESTIGATION OF STATE, TRENDS AND STRUCTURE OF THE WORLD MARKET OF NANOPOWDERS

Об'єктом дослідження є стан, тенденції та структура світового ринку нанопорошків. Одним із найбільш проблемних місць є неоднозначність літературних даних за цією тематикою. Систематизація наявних літературних даних дозволить вирішити дану проблему.

Для проведення маркетингового аналізу застосовано метод пошуку літературних даних з досліджуваної тематики та метод аналізу. Проведений аналіз літературних джерел дозволив визначити наноматеріали, як найбільш комерційний сектор сучасного ринку нанотехнологій. Представлено відомості про найбільш поширені у світовому просторі нанопорошки металів та оксидів, а також галузі їх застосування. Показано, що складні нанопорошки, які складаються із сумішей оксидів, мають обмежену сферу застосування. Склад, розмір і форма частинок нанопорошків залежать від методу одержання та умов проведення процесу.

Здійснено прогноз питомої ваги різних країн світу на ринку нанопорошків та потенційний попит на нанопродукти у майбутньому. Показано структуру інвестицій за галузями промисловості та прогнозований обсяг ринку нанотехнологій. Наведено структуру ринку нанопорошків за напрямками використання та за видами нанопорошків.

При проведенні дослідження застосовано метод систематизації та класифікації. Систематизовано дані щодо світового обсягу виробництва нанопорошків за природою металів та структурою їх виробництва за розмірами частинок. Загальною проблемою на ринку нанотехнологій є висока вартість продукції та низький обсяг виробництва. Висока вартість нанопрошків визначається значною вартістю вихідної сировини і малим обсягом виробництва. На обсяги споживання нанопорошків впливає та чи інша галузь їх використання. Показано структуру споживання нанопорошків за галузями на світовому рівні, близько 70 % споживання припадає на електроніку, оптику та оборонну промисловість.

Систематизація літературних даних дозволила представити проблематику нанопорошків у вигляді таблиць та діаграм, що дає певну перевагу для усвідомлення та використання матеріалу.

Ключові слова: *маркетингове дослідження, структура ринку, світовий ринок нанопорошків, фактори при ціноутворенні, виробництво нанопорошків.*

1. Introduction

Nanopowder is a mass of dry nanoparticles with external dimensions in all three dimensions of the nanorange, from about 1 nm to 100 nm. Unlike other types of nanomaterials (nanotubes, fullerenes, nanopores, etc.), nanopowders are made from many types of raw materials. At the same time, nanopowders can have both similar feedstock characteristics and special properties due to the size and structure of their particles. The total global consumption of nanomaterials exceeded 15 billion USD. The nanopowder industry is the most developed commercial sector of the nanomaterials market. The average annual increase is 15 %.

Therefore, marketing research of the nanopowder market is an urgent task for the development of the nanotechnology industry.

2. The object of research and its technological audit

The object of research is the state of trends and the structure of the world market of nanopowders.

The following main types of nanoparticles are distinguished [1]:

– metal nanoparticles – nanoparticles from metals (alloys), in particular titanium, iron, copper, aluminum, gold, silver, and the like;
– oxide nanoparticles – nanoparticles of aluminum oxide, titanium, iron, zinc, zirconium, etc., are used, for example, in the formation of bulk oxide ceramics and coatings in polishing, cosmetic and other products;
– nanoparticles of oxygen-free ceramics – nanoparticles based on carbides, nitrides, silicides, other compounds, which are used, for example, in the formation of bulk oxygen-free ceramics and coatings, in polishing, antifriction and other products.

Unlike other types of materials (nanotubes, fullerenes, nanoporous materials), nanopowders are made from many types of raw materials. Table 1 presents information on the most common nanopowders of metals and oxides in the global space.

In the form of powders almost all types of solid metallic elements are produced. Costs in the production of homogeneous powders of metals with a high degree of purity are significantly higher than in the production of metal oxides. Table 2 shows data on the use of pure metals in various fields.

Table 1

Applications of nanopowders of metals and oxides

Compound	Formula	Scope of nanopowders
Silicon oxide	SiO_2	– electronics; – optics; – manufacturing industry (abrasive); – production of paintwork materials (paints and varnishes); – as a plastic filler, coating, primer for building materials, as a water repellent, etc.
Titanium oxide	TiO_2	– manufacturing industry; – production of paints; – optics (photocatalysts, lens coating); – environmental protection (wastewater treatment, air filters); – production of building materials; – production of plastics (white dyes); – production of glass, mirrors; – utilization of chemical missile warheads
Aluminium oxide	Al_2O_3	– manufacturing industry (abrasive, blast cleaning); – electronics (lapping, polishing, capacitor manufacturing); – optics (wiping, polishing); – air purification (catalyst); – production of structural ceramics
Iron oxide	Fe_2O_3 Fe_3O_4	– production of glass and ceramics, chemical reaction catalysts, magnets and memory devices; – water purification
Zinc oxide	ZnO	– production of polymers, hydrogen fuel cells and solar cells; – cosmetology; – textile production
Cerium oxide	CeO_2	– production of hydrogen fuel cells and glass; – optics (wiping, polishing)
Zirconium oxide	ZrO_2	– production of ceramics; – production of hydrogen fuel cells
Yttrium oxide	Y_2O_3	– refractory ceramics; – production of fluorescent lamps; – production of hydrogen fuel cells; – display and monitors; – sensors in the automotive industry
Copper oxide	CuO	– electronics; – optics; – biology; – medicine
Magnesium oxide	MgO	– production of antibiotics, coatings, dressings, polymers, alloys and metals; – textile production; – production of fungicides; – electronics; – optics; – biology; – medicine
Neodymium oxide	Nd_2O_3	– electronics (ceramic capacitors, phosphors, electrodes, magnets); – optics; – glass production
Europium oxide	Eu_2O_3	– electronics (phosphors of color TVs and X-ray screens); – optics; – production of graphite rods of nuclear reactors
Dysprosium oxide	Dy_2O_3	– electronics; – optics; – production of magnets and memory devices; – production of halogen lamps

Note: systematized and summarized by the authors on the basis of predicted literature data [2, 3]

Table 2

The use of metal nanopowders in various industries

Metal	Formula	Scope of nanopowders	Spread
Nickel	Ni	– cheap platinum substitute; – production of hydrogen fuel cells, coatings, polymers and textiles; – electronics; – optics; – medicine	High
Copper	Cu	– biology; – medicine; – electronics; – optics	
Iron	Fe	– water purification; – production of magnets and storage devices, coatings, polymers; – optics; – biology; – medicine	
Aluminum	Al	– cheaper titanium substitute; – catalysts; – biology; – the medicine	
Titanium	Ti	– biology; – medicine; – additives for stability when exposed to UV rays; – production of coatings	
Cobalt	Co	– production of glass and ceramics; – optics; – medicine	
Zinc	Zn	– biology; – medicine; – production of polymers, textiles, hydrogen fuel cells and solar panels	Medium
Tungsten	W	– production of coatings; – production of polymers	
Molybdenum	Mo	– catalysts (carbon nanotubes); – production of coatings, polymers, inhibitors and lubricants	
Silver	Ag	– biology; – medicine; – pharmaceutics; – textile industry; – coating; – air filters (catalysts)	Low
Gold	Au	– electronics (wire contacts, electroplating, protection against infrared radiation); – catalysts; – medicine; – biology; – pharmaceutics	
Platinum	Pt	– electronics (catalyst); – production of hydrogen fuel cells and fiberglass; – automotive industry; – oil and gas industry; – medicine; – biology; – pharmaceutics	
Silicon	Si	– electronics (the main component of semiconductors, microchips and solar cells); – metallurgy (additives to ensure heat resistance); – production of ceramics, pyrotechnics, cement and abrasives, etc.	

Note: systematized and summarized by the authors on the basis of predicted literature data [2, 3]

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Complex oxides and nanoparticle mixtures make up a relatively small fraction of the manufactured nanopowders. Unlike pure metals and their oxides, complex nanopowders have a limited scope. There are such types of mixtures and complex oxides [4]:

– antimony tin oxide (Sb_2O_3/SnO_2) – used in electronics and optics; an important component of displays due to the antistatic effect; the ability to absorb the infrared part of the spectrum, photoconductivity;
– indium tin oxide (In_2O_3/SnO_2) – used in the manufacture of displays as part of transparent conductive coatings;
– silicon nitride (Si_3N_4) – used in the manufacture of turbines, engine parts, machines, heat-resistant and heat-insulating materials, as well as heat and corrosion-resistant clamps;
– barium titanate ($BaTiO_3$) – used in electronics in the manufacture of memory devices, electrical amplifiers and ferroelectric ceramics;
– nanodiamonds (C) – used in the manufacturing industry for applying coatings on polishing and cutting tools, drills, for the manufacture of lubricating and wear-resistant coatings; additives to steel; semiconductor manufacturing;
– tungsten-cobalt carbide (WC/Co) – additives to tools, in particular, metalworking and mining.

Compared with the feedstock, nanopowders have a low sintering temperature, are chemically active, have excess energy.

Nanopowders are obtained by chemical, physical, physicochemical, and mechanical methods.

Chemical methods consist of several successive stages:

– sedimentation is carried out from solutions of salts with the help of precipitating agents (solutions of alkalis – sodium and potassium hydroxides), acids, and the like. Regulation of pH and temperature of the solution allows to control the processes of crystallization and to ensure high dispersion of the hydroxide. The gel method is used to obtain powders of various metals. It consists in the precipitation of gels of insoluble metal compounds from aqueous solutions;
– thermal decomposition and recovery is the process after deposition and drying of nanodispersed oxides or hydroxides. Depending on the product requirements, gaseous (hydrogen, carbon monoxide) or solid reducing agents are used. The method allows to obtain spherical, needle, scaly or irregular powders. Nanopowders of Fe, W, Ni, Co, Cu and other metals are reduced in different environments, depending on the tasks.

Physical methods are based on the evaporation of metals, alloys and oxides with their subsequent condensation at a controlled temperature and atmosphere. The vapor – liquid – solid phase or vapor – solid phase transitions occur in the reactor or on a cooled base (walls). The starting material is evaporated by intense heating and the carrier gas is fed into the reaction chamber, where it is subjected to rapid cooling. Heating is carried out using plasma, laser radiation, electric arc, resistance furnaces, induction current, and the like.

Depending on the type of source material and the product obtained, evaporation and condensation are carried out in vacuum, inert gas flow or in plasma. The size and shape of the particles depends on the process temperature, the composition of the atmosphere and the pressure in the reaction medium. For example, in an atmosphere of helium particles are smaller in size than in an atmosphere of more dense gas – argon. The method allows to obtain powders of Ni, Mo, Fe, Ti, Al with a particle size in the nanometer range.

The method of producing nanomaterials by electrical explosion of conductors is known. A metal wire with a diameter of 0.1–1.0 mm is placed in the reactor between the electrodes, to which a powerful current pulse of $1.04–1.06 \cdot 10^8$ A/m^2 is applied. There is an instant warm-up and evaporation of the wires. The metal vapors fly away, cool and condense to form a nanopowder. The process is carried out in an atmosphere of helium or argon. So get nanopowders of metals (Ti, Co, W, Fe, Mo) and oxides (TiO_2, Al_2O_3, ZrO_2) with a particle size of up to 100 nm.

Mechanical methods are the grinding of materials in mills (ball, planetary, centrifugal, vibration), gyroscopic and other devices. Mechanical grinding is used in the production of nanopowders of metals, ceramics, polymers, oxides, and other brittle materials. The degree of grinding depends on the nature of the materials and on the equipment that is used.

The mechanical method is the simplest, most productive and affordable. Basically, receive powders of alloys of metals. Disadvantages are the likelihood of contamination upon receipt of powders in a nanodispersed state and the complexity of regulating the composition of the product.

One of the main problems in the production of nanopowders is the tendency of nanoparticles to form aggregates and agglomerates, which make it difficult to obtain compact materials. To overcome the agglomeration forces, it is necessary to apply a mechanical force or increase the sintering temperature.

Available data on the scope of nanopowders of metals and oxides require further comprehensive analysis of the global market for a more detailed disclosure of the topic and aim of research.

3. The aim and objectives of research

The aim of research is a comprehensive analysis of the global market of nanopowders.

To achieve this aim it is necessary to perform the following tasks:

1. Search for potential demand, as well as the size of the nanotechnology market in different countries.
2. Summarize the state and development trends of the world nanopowder market.
3. Carry out the price analysis of the market of nanopowders.

4. Research of existing solutions of the problem

Achievements in the development and manufacture of nanostructures are largely determined by the level of technology development, allowing to obtain nanostructures of the required configuration and dimension. A necessary requirement is the development of methods for complex diagnostics of the properties of nanostructures, including control in the manufacturing process (insitu) and control of technological processes on its basis. According to many forecasts, it is the development of nanotechnology that will determine progress in the 21st century, just as the discovery of atomic energy, the invention of a laser and a transistor determined progress in the 20th century [2, 5].

Currently, this industry is powerfully developing in three areas:

1) manufacture of electronic circuits (including bulk ones) with active elements whose dimensions are comparable to the size of single molecules or atoms;

2) development and manufacture of nanomachines, that is, mechanisms and robots of molecular sizes;

3) production of nanopowders [6, 7].

Among the main directions of solving the problem of marketing research of nanopowders identified in the world resources of scientific literature, the works [8, 9] can be highlighted. As well as well-known works [10, 11]. But in the literature data the issues of obtaining nanopowders of metals and their oxides by the electrolysis of ionic liquids are not sufficiently considered. The authors of [12, 13] make the first attempts to systematize methods for producing nanopowders and marketing research of the nanopowder market. Recently, significant use of nanopowders has occurred in biology and medicine [5, 14]. Some attempts at market research of nanopowders and design decisions (composition, structure, particle size) are made in [15, 16].

In this paper, let's use generally accepted approaches to marketing research in the industry, which are presented in [17, 18]. In [19, 20], promising areas in the field of industrial marketing are presented. Recent attempts to generalize the characteristics of existing metallic nanopowders and the industries of their application are presented in [21, 22]. A review of articles and patents in this matter was made in [23, 24]. The main characteristics of nanopowders (including nitride and titanium carbonitride, obtained by plasma-chemical synthesis) were considered in detail in [25]. The use of nanopowders of aluminum and its compounds as high-energy materials is promising [26, 27]. The addition of oxide nanoparticles to polymer matrices is important for the optics and electronics industries [28]. A significant development of nanotechnology has the electronics industry [29, 30]. The promising use of the latest technologies in the field of nuclear energy [31] and the food industry [32] is well known.

The works [33, 34] are devoted to the development of concepts of development, achievement and the most promising areas of development in the field of nanotechnology. The level of research on this industry in different countries and the existing government programs for the development of the industry are given in [35, 36]. Special attention has recently been paid to environmental protection [37] and the development of biomedicine [38]. Some attempts to address the issues of business and pricing in the field of nanotechnology are made in [39, 40].

Thus, the results of the analysis of literature data allow to conclude that it is necessary to further systematize the material according to the scope and marketing research of the nanopowder market.

5. Methods of research

The following scientific methods are used in this research:

– method of searching for literature data on the subject under investigation;

– analysis method when conducting marketing research in the field of nanomaterials and nanotechnologies;

– method of systematization and classification when conducting research on the achievements of modern science in the field of nanoindustry.

6. Research results

6.1. World nanotechnology market review. The state and prospects of development of the nanopowder market associated with the overall dynamics of the nanotechnology sector. The nanotechnology market is developing rapidly, as evidenced by the growth of investment in the industry, as well as the number of scientific developments, patents and publications on this issue. The number of companies that represent nanotechnology, as well as the volume of commercially marketable products, increases annually. Achievements of nanotechnology today use various industries [4].

Thus, according to estimates by consulting company Lux Research, in 2012 the volume of the nanotechnology market was 190.3 billion USD [3]. Its annual increase is 15–17 %. The products obtained using nanotechnologies account for about 0.05 % of the global gross aggregate product, it is expected to grow to 1.5 % by 2020. The world market leaders are the USA (59 billion USD), Europe (47 billion USD) and the Asia-Pacific region (9.4 billion USD). The United States leads both in terms of the volume of the commercial market and the number of publications (about 25,000 in 2015) and nanotechnology patents (45 % of patents).

Distribution of spheres of influence in the field of nanotechnology, according to the US NanoBusiness Alliance, is already happening and will be completed by 2020 [3]. The predicted structure of the world market will look like this (Fig. 1). The largest commercial sector in 2015 is the production of nanomaterials (126 billion USD). The leader in this sector is the manufacture of nanocomposites, which are used in the automotive industry and construction. In second place is electronics (45 billion USD). Almost 19 billion USD is in the health care industry.

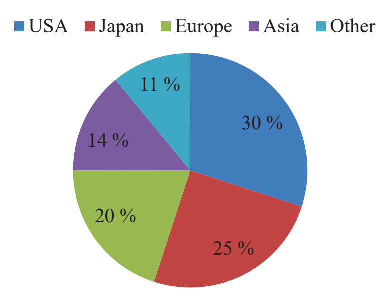

Fig. 1. The predicted share of different countries on the nanotechnology market in 2020 [3, 41]

The demand for nanoproducts, according to Lux Research, will be distributed until 2020 between the directions of the nanoware market, as shown in Fig. 2. It can be seen that nanomaterials and nanoelectronics products will be in the greatest demand. The largest consumer of nanoproducts will be the Asia-Pacific region, the United States and Europe.

At the end of 2015, products were manufactured, including developments in the field of nanotechnologies worth more than 1.4 billion USD. The chemical industry, research (intermediate products, as a rule, not serial) and electronics are leading in the production structure of nanoproducts.

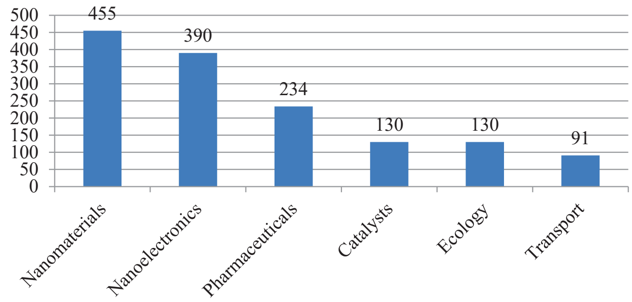

Fig. 2. Potential demand for nanoproducts in 2020 (billion USD) [3, 41]

There is a tendency for the growth of companies in the nanotechnology sector, which is on average 30–40 % higher than the dynamics of the world market as a whole.

The volume of global investment in nanotechnology in 2015 amounted to 18.1 billion USD. This figure has increased compared with 2013 by 18 %. Corporate investment (8.6 billion USD) became the main source of funding (public – only 8.3 billion USD). The proportion of venture capital has decreased (1.0 billion USD). The largest volume of investments goes to the chemical sector and the pharmaceutical industry. According to the forecasts of the company Cientifica (Fig. 3), by 2018 this structure may undergo some changes: pharmaceuticals play a leading role – funding for projects in this area will increase fivefold [3, 41]. There will also be a tendency to double growth in the field of electronics. The leaders in terms of public investment are the US and the EU. According to experts, in the long term to 2020, the leadership in terms of the volume of investments can go to Japan. Today, the leader in the nanomaterials market is the United States with a projected income level of 2018 in the amount of 1.46 billion USD. The second largest sector is Western Europe. The most rapidly growing and promising segment is the Asia-Pacific region.

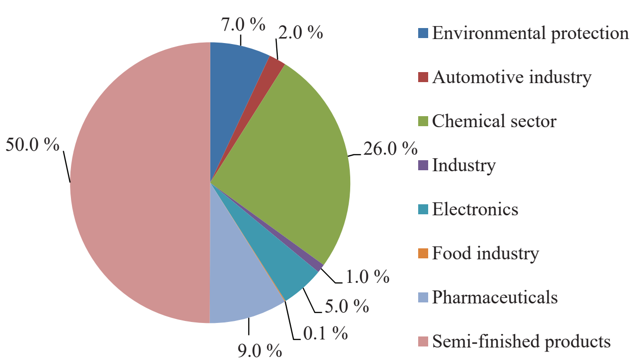

Fig. 3. The structure of investment by the industries [3, 41]

In general, it is worth noting that today's production of nanomaterials does not meet the needs of the market. The projected growth volumes of each of the component spheres associated with increased availability of nanomaterials for the end user.

The prospect of the nanotechnology market looks optimistic. At the same time, experts estimate its capacity and growth dynamics in different ways. The volume of the nanotechnology market and its forecast in trillion USD are presented in Table 3. It can be seen that the prediction of the global nanomarket volume is different. Firstly, the risks associated with the production of nanoproducts have not been studied. Secondly, the assessment of market prospects is based on the position of a possible «breakthrough» in some industries, for example, inventions of nanocomputers, nanorobots, improvement and increase in the production of nanotubes, products for biomedicine, etc. [42].

Table 3

The projected volume of the nanotechnology market, trillion USD

Expert organization	The projected volume of the nanotechnology market, trillion USD
Mitsubishi Institute, forecast for 2018	0.19
European Commission, forecast for 2018	0.26
Iunkett Research, forecast for 2017–2020	1.3
Lux Research, forecast for 2018	3.4
Us NanoBusiness Alliance, forecast for 2020	1.3
Forecast for 2020	2.0

Note: developed on the basis of predicted data [3, 41]

6.2. State and development trends of the world nanopowder market. Industrial production of most types of nanopowders began 10–15 years ago. In industrial quantities only silica, alumina and iron oxide were obtained. Research institutes and universities received small samples of nanopowders for research. Today, technologies for producing nanopowders for manufacturing a wide range of materials have been developed. In this case, the powders may differ in fractions and purity of the material. The production of nanopowders is the most extensive [42, 43], compared with the production of other nanomaterials. Despite the large range of powders that are available, only some of them are produced on an industrial scale [44, 45]. The volume of the world market of nanopowders, which are used in the energy sector as catalysts in the production of construction materials, in 2016 amounted, according to BCC Research [46], to 474.4 billion USD. The increase compared with 2015 – 17 %. At a compound annual growth rate (CAGR) of 38.7 %, by 2020 market volume will be at the level of 17 billion USD. There are three main areas of application of nanoparticles on the market (Table 4):

1) use in electrical appliances;
2) as catalysts;
3) in construction materials.

Table 4

Nanopowder market structure by application

Application	2012		2017		
	million USD	% of total	million USD	% of total	CAGR 2013–2017, %
Catalysts	260.1	55.0 %	464.5	26.6 %	12.2 %
Power industry	76.4	16.1 %	785.5	45.0 %	59.4 %
Construction materials	137.2	28.9 %	496.6	28.4 %	29.4 %
Total	473.7	100.0 %	1746.6	100.0 %	29.8 %

Note: developed on the basis of predicted data [3, 41]

In addition to these industries, an important market segment is the use of nanopowders in electronics, optics, and the like.

6.3. Market structure.

6.3.1. Nanopowder market structure in different countries. The main consumers of nanopowders in the world are the countries with the most developed nanoindustry – the USA, Japan and the EU.

The global production of nanopowders is unevenly distributed. The main production facilities are located in developed countries. At the same time, countries such as Brazil, South Africa, etc., have a high raw material potential, but do not produce nanopowders in significant quantities.

More than two thirds of the global production of nanopowders is made in the USA, where almost half of all manufacturers are located. The United States provides consumer products in Europe, and to a lesser extent in Asia.

However, many US manufacturers are small innovative companies or research institutes that synthesize nanopowders for internal needs. In Asia, by contrast, a small number of market participants have large production volumes. The Asian region has huge reserves of rare earth metals, such as yttrium, zirconium, and others.

In Europe, the most developed nanoindustry in Germany and the UK. The main problem in Europe in the near future may be a shortage of raw materials, since, in particular, deposits of rare earth metals in the region are limited.

6.3.2. Nanopowder market structure by type of nanomaterials. The main type of products on the world market of nanopowders is metal oxide powders (Fig. 4). In the commodity group of metal oxides, 4/5 of the production volume falls on the three most common raw materials: silica (SiO_2), titanium dioxide (TiO_2) and alumina (Al_2O_3). At the same time, silica occupies more than half of the total production, alumina – 18 % and titanium dioxide – 10 %. The most available oxides are oxides of iron, zinc, cerium, zirconium, copper, magnesium and yttrium.

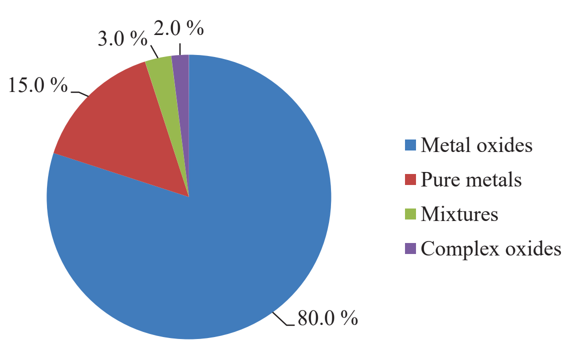

Fig. 4. The structure of nanopowders in the world market [3, 41]

In the pure metal nanopowder market, 16.5 % of the production volume falls mainly on nickel and copper powders. Among the leaders in this indicator are iron, aluminum and titanium (from 13 % to 14 %) (Fig. 5).

Among the complex oxides and mixtures of all, antimony-tin oxide, barium titanate, cobalt carbide, silicon nitride and indium-tin oxide are produced.

Analysis of papers [47, 48], which are devoted to research in the field of nanopowders shows that the most promising direction of scientific research is nanopowders of aluminum and precious metals.

The structure of nanopowder production in the regions is about the same. Thus, in Europe, metal oxide powders produce more in volume (more than 90 %), and in Asia – more pure metal powders (up to 25 %).

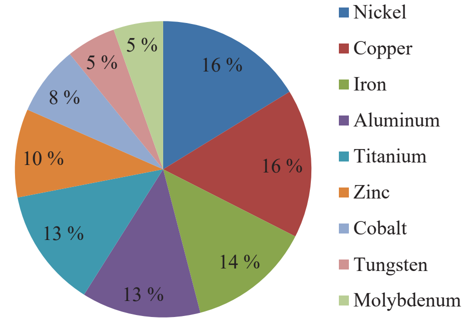

Fig. 5. World production of pure metal powders [3, 41]

Five leading manufacturers from North America (for example, American Elements) produce more than 20 types of nanopowders, while in Europe and Asia the assortment rarely exceeds 10 items (usually 1–5 items). Most of the powders are produced in limited quantities due to the order for research purposes.

The particle size of nanopowders is not a major factor in pricing. More than half of all nanopowders (up to 60 %) have a particle size of less than 60 nm, and about 40 % less than 30 nm (Fig. 6).

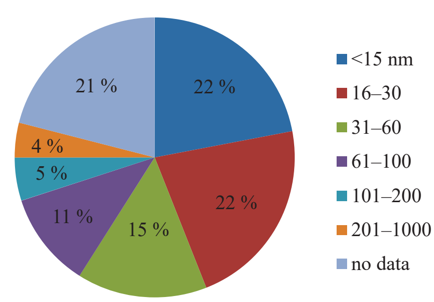

Fig. 6. Structure of nanopowder production by size of nanoparticles [3, 41]

6.4. Price analysis. The market of nanopowders is difficult for price analysis, due to the following reasons [4, 41]:

– manufacturers cooperate with certain industries, therefore, produce nanopowders with different characteristics (fraction, purity, etc.);

– in the production of nanopowders with controlled properties in determining the price is an important indicator of the volume of the party.

The cost of nanopowder at the conclusion of each contract is determined individually. The estimated cost of some common nanopowders is shown in Fig. 7.

Thus, the high cost of nanopowders of zirconium oxide, silver oxide and indium tin oxide is determined by the high cost of the raw materials and small production volumes. The cost of manufacturers differs by 25–30 % and depends, in particular, on transportation costs upon delivery to the consumer.

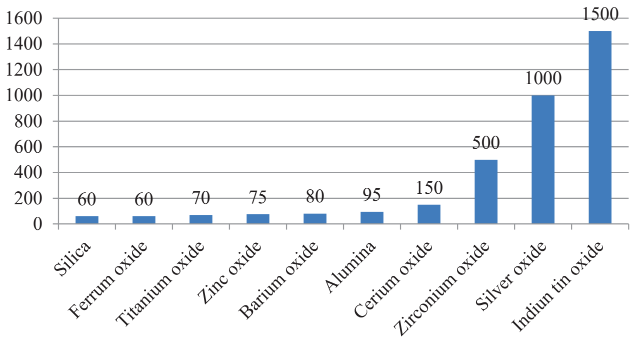

Fig. 7. The average cost of nanopowders, USD/kg [3, 41]

6.5. Peculiarities of nanopowder consumption. Nanopowders are not always the final product, but are used in various industrial processes. Accordingly, the volume of consumption of nanopowders affects one or another area of their use.

Today, nanopowders are regularly used in two key areas: in electronics (mainly silica) and in the manufacturing industry. In other industries, demand for nanopowders exists in the form of one-time orders.

The structure of nanopowder consumption by industry at the global level is presented in Fig. 8. It can be seen that the demand for nanopowders is formed mainly by the electronics and manufacturing industries. Methods of using nanopowders in these areas are almost the same, for example, they are used as an abrasive.

Table 5 systematizes the field of application of nanopowders classification of their use, development stage and the proposed forms on the market.

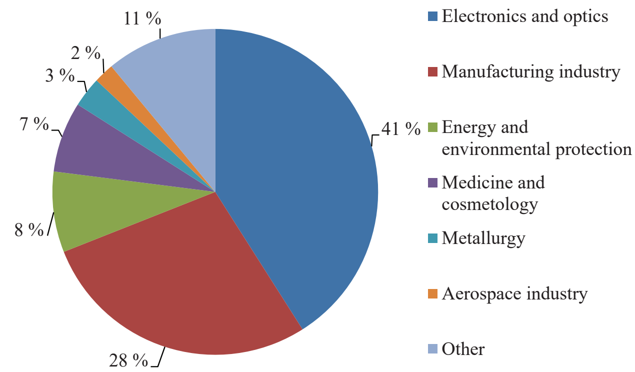

Fig. 8. Consumption of nanopowders by the industries [3, 41]

The main branches of practical use of nanopowders today are: electronics (functional coatings, combined and composite materials), energy (automotive catalysts), health care and medicine (surgery and oncology), engineering (polymeric materials and composites). So far, to a lesser extent, the achievements of nanoindustry are used in the production of consumer goods and environmental technologies.

Table 5

Branches of practical application of nanopowders

Application branch	Development stage	Forms offered in the market	Application
Power industry	Nanocrystalline nickel, copper and metal hydrides for chemical current sources; solar panels; hydrogen batteries solid oxide fuel cells	Environmental catalysts, cerium oxide in diesel engines	Automotive catalysts
Health and medicine	Nanocrystalline drugs; nanospheres using biocompatible silicon bone growth accelerators; virus detection and use of quantum dots; agents in the treatment of oncology; implant coatings	Sunscreens using ZnO and TiO_2; molecular labeling: quantum dots, CdSe; carriers for drugs with low solubility in water	Au, Ag, Pt, ZnO, Fe, surgery, oncology, therapy, etc.
Engineering	Cutting parts of tools with: WC, TaC, T & C, Co; spark plug; dielectrics; herbicide and pesticide delivery; sensors; molecular sieves	Abrasive-resistant coatings with Al_2O_3 and Y-Zn_2O; polymer composites reinforced with nanoclays; oils; pigments; self-cleaning glass with TiO_2; jet fuel	Structural building of polymers and composites; gas-thermal coatings based on: TiO_2, TiC-Co, etc; ink
Consumer goods	–	Anti-counterfeit devices	Sporting goods; packaging; cover
Ecology	–	Nanostructured coatings; photocatalytic water purification	Coated tiles; sanitary goods; soil restoration (with Fe, Al, Ce)
Electronics	Nanoscale magnetic particles for high density drives; protection from internal radio interference; electronic circuits; display technologies	Ferromagnetic fluids; optoelectronics devices; conductive coatings	Coatings and binders

Note: developed based on predicted data [2, 3, 41]

7. SWOT analysis of research results

Strengths. In this paper, the systematization and analysis of literature data in the field of modern production of nanopowders and the prospects for their production, as well as marketing research of the market of nanopowders, are carried out simultaneously. The combination of these data makes it possible to more reasonably reveal the issues of the current state and prospects of the market for nanomaterials and nanotechnologies.

Weaknesses. The lack of reports on this topic in the public domain.

Opportunities. Further research will be focused on using the results of the analysis of the global nanopowder market for the formation of the Ukrainian nanopowder market. Advances in nanotechnology are the result of research from many countries. Therefore, the experience of a particular country is very useful for the development of its own nanoindustry.

Threats. The rapid development of nanotechnology makes some adjustments to various aspects of marketing research on nanopowders.

8. Conclusions

1. A search for countries for the production of nanopowders is done. It is shown that the most developed nanopowder markets are the USA (the volume of the nanotechnology market is 60 billion USD), Europe (47 billion USD) and the Asia-Pacific region (10 billion USD).

2. The state and development trends of the world nanopowder market are reviewed. The United States (2/3 of the world output), Asia (mainly Japan) and Europe (Germany and the United Kingdom) dominate the global nanopowder market. In countries with high raw material potential (Brazil, Mexico), production is practically undeveloped. The specificity of the world market of nanopowders is that Europe produces more in volume of powders of metal oxides (more than 90 %), and in Asia – powders of pure metals (up to 25 %), the range of American manufacturers, as a rule, exceeds that in European and Asian countries.

3. The price analysis of the world market of nanopowders allows to identify the following indicators characterizing its development:

– nanomaterials – the largest commercial sector of the modern nanotechnology market with a volume of about 100 billion USD; the chemical industry, research (intermediate products, as a rule, not serial) and electronics are leading in the structure of nanoproduction;

– common problem in the nanomaterials market – the high cost of products, low production volume and availability for the end user;

– volume of the three largest components of the nanomaterials market – energy, production of catalysts, structural materials is 375 million USD; projected growth rates for 2015–2020 – 60 %, 13 % and 30 % respectively;

– on the world market of nanopowders, production of products from metal oxides dominates; common types of raw materials: silica (SiO_2) – more than half of the total production, titanium dioxide (TiO_2) – 10 % and alumina (Al_2O_3) – 18 %;

– among pure metal nanopowders, more than 30 % is accounted for by the production of nickel and copper powders; iron, aluminum and titanium (13–14 %) are among the leaders according to this indicator;

– more than half of all nanopowders has a particle size less than 60 nm, and more than 40 % – less than 30 nm;

– demand for nanopowders is formed mainly by the electronics and manufacturing industries. The largest volume is in the market of nanoscale in medicine and cosmetology.

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