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Original Research Paper

Plasma dynamic synthesis and obtaining ultradispersed zinc oxide with single-crystalline particle structure

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ABSTRACT

Zinc oxide is well-known semiconductor material having good electrical, optical and catalytic properties. This paper shows the results on synthesis of hexagonal zinc oxide with single-crystalline particle structure using the system based on coaxial magnetoplasma accelerator. The synthesis is implemented during one short cycle (up to 10^{-3} s) of plasma accelerator work. X-ray diffractometry analysis allow us to confirm that the product consists of only hexagonal zinc oxide with lattice parameters $a = b = 3.24970$ Å, $c = 5.20270$ Å. This result is in a good agreement with EDAX data, which show the presence only Zn and O elements in the final product. SEM, TEM and HRTEM methods are used to investigate the particles morphology. It is found that the product consists of single-crystalline hexagonal particles of zinc oxide and electron diffraction from particles also confirmed the zinc oxide structure. The particle sizes are up to 350 nm but the most of the particles (85%) are less than 150 nm.

1. Introduction

For the last 10 years, there has been an increasing interest in researches connected with investigation of nanomaterials, in particular metal oxides, due to their wide range of potential application areas [1–5]. In this group, it is possible to point out zinc oxide, which is well-known by its good electrical, optical and catalytic properties [6]. This is the reason for investigations of its nanostructures. Many research teams assert that zinc oxide nanostructures can be used in different areas, from cosmetics to drug delivery and biosensors [7–13].

It is worth noting that one of the most important requirements for ZnO nanopowders is their single-crystalline structure. More over, synthesis and characterization of such nanoscale materials are still inalienable and important task for better understanding the properties, which depend on both size and shape of particles [14–16]. For example, nanosize properties become less dominant in comparison with bulk properties, when the size of nanoparticles increases over 100 nm. [17]. In spite of this, there are some scientific areas, where there is a special interest in obtaining the particles having special forms with the wide enough distribution from tens to hundreds of nanometers [18].

To date, there are many different ways to obtain nanoscale zinc oxide. It includes chemical [19,20], mechanical [21,22], thermal [23,24] methods as well as green synthesis [25,26]. Nonetheless, in spite of numerous reports about synthesis of zinc oxide nanopowders using plasma-based methods, plasma chemical processes are not so widespread. Ultradispersed and nanodispersed single-crystalline structures can also be obtained by crystallizing from the liquid phase at a high-speed quenching the material under supersonic spraying in the gaseous atmosphere [27]. Such conditions occur during implementing plasma dynamic method based on the use of a pulsed high-current coaxial magnetoplasma accelerator (CMPA) of the erosion type. The main advantages of this method are one-step nature of the process, its duration and obtaining the single-crystalline product that did not require further purification and processing.

This work reports the plasma dynamic synthesis that allows us to obtain ultradispersed zinc oxide in the one short cycle (up to 10^{-3} s) of CMPA work. For providing the necessary conditions to implement the synthesis process in Zn-O system, the CMPA design was remade by changing the electrode system and its construction. Using XRD, HRTEM and EDAX, we found that the synthesized product consists of single-crystalline hexagonal ZnO particles with the necessary stoichiometry. The particle size distribution histogram allows us to affirm that the product has the broad distribution up to 350 nm.

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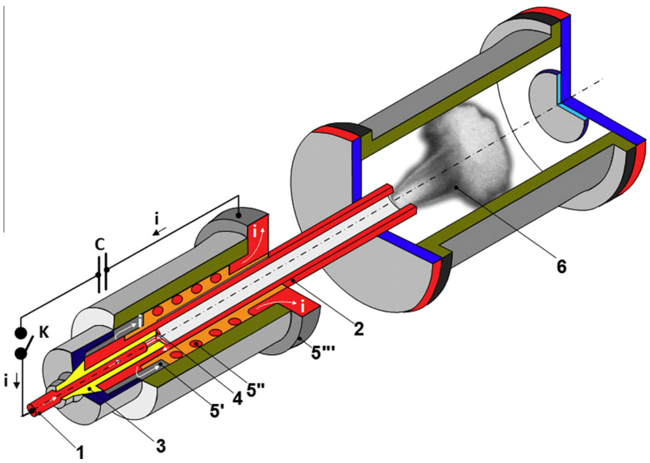

Fig. 1. Plasma dynamic synthesis system based on pulsed high-current coaxial magnetoplasma accelerator (CMPA) of the erosion type: 1 – central electrode; 2 – electrode barrel; 3 – insulator of central electrode; 4 – plasma formation zone 5 – inductor (5′-pin cylinder, 5″-coil, 5‴-pin flange) 6 – chamber-reactor.

2. Experimental

2.1. Method

The system for plasma dynamic synthesis is schematically shown in Fig. 1. The main part is a pulsed (up to 10^{-3} s), high-current (about 10^5 A) coaxial magnetoplasma accelerator (CMPA) of the erosion type. The tip of the central electrode 1 and the accelerating channel 2 (AC) are made of metallic zinc (Zn). In the initial state, the central electrode and AC are electrically connected with each other through Zn electro explosive wires. Fountain-like beam of wires is placed into the fiberglass insulator 3, which forms the cylindrical plasma formation zone 4. The cylindrical AC, placed into the inductor 5, has the following design parameters: diameter d_{AC} = 10 mm, length ℓ_{AC} = 200 mm. CMPA accelerating channel enters to the airtight chamber-reactor 6 (diameter d = 300 mm, ℓ = 700 mm, volume V = 0.05 m^3) filled with oxygen at atmospheric pressure and room temperature.

CMPA is supplied from the capacitive energy storage (C = 4.8 mF) at a charging voltage U_{ch} = 3.4 kV and accumulated energy W = 27.7 kJ. Fig. 2 shows typical waveforms of the discharge current $I(t)$, the voltage at the accelerator electrodes $U(t)$, the

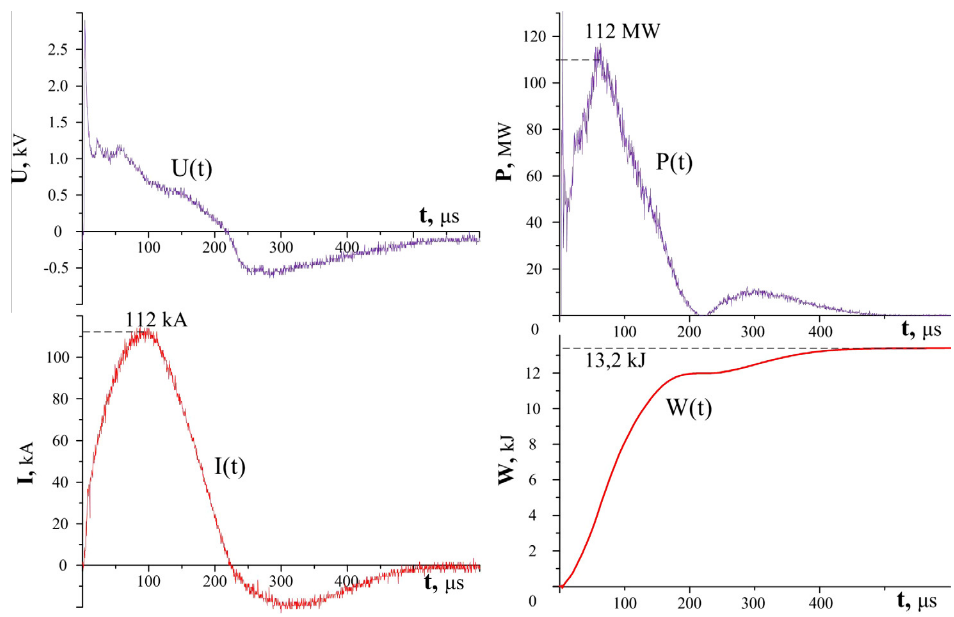

Fig. 2. Typical oscillograms of current $I(t)$, voltage between electrodes $U(t)$ and curves of discharge powder $P(t)$ and input energy $W(t)$.

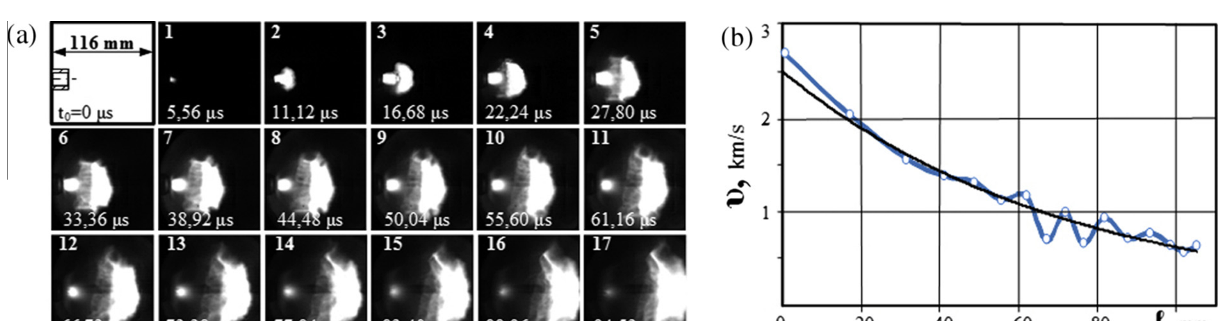

Fig. 3. (a) typical photogram of pulsed high-speed electro discharge plasma jet flowing from AC and (b) attenuating curve of bow shock wave front speed with increasing distance from the AC edge.