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Detonation synthesis of zinc oxide nanometer powders

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Abstract

Novel zinc oxide nanometer powders have been synthesized via detonation reaction with respect to the presence of an energetic precursor, such as lithium nitrate and zinc nitrate. The detonation products of emulsion explosives were characterized by powder X-ray diffraction. Transmission electron microscopy was used to observe the structures. Zinc oxide with primary particles of diameters from 20 to 50 nm and a distribution with proportional spacing of spherical morphologies were found. The oxides produced by this cheap method affirmed the validity of detonation synthesis of nanosize powders. It is concluded that unconventional emulsion explosives are designed uniquely for synthesis of the nanometer zinc oxide.

Keywords: Nanomaterials; Crystal structure; Zinc oxide; Detonation synthesis; X-ray techniques

1. Introduction

A zinc oxide is the subject of growing interest for different applications in electronic components [1-4]. Especially, Ceder et al. regarded that $LiZnO_2$ compound has a higher voltage than that of $LiCoO_2$ [5]. More recently, it was reported that these oxide nanomaterials have generated tremendous interests in both the scientific and engineering community, which has visibly led to rapid and intense growth in research focus [6-13].

In this paper, we report the synthesis of oxide nano-powder, which we believe, has never been reported. We can grow these nanoscale structures in a cheap manner through the addition of nitrates using the emulsion explosive detonation process. This novel method allows us to synthesize nanometer oxide powders.

Liu et al. [14] thought that the shock-induced chemical reactions leading to synthesis of compounds in powder mixtures occurred under conditions of the microsecond-scale duration of the high pressure, high strain rate, and high temperature states. Such high-rate chemical reactions can be advantageously utilized to synthesize materials with novel phases and unique microstructures, or to generate radically modified materials with physically interesting or technologically useful properties.

Davidson et al. [15] reported that using solid-state reactions method, usually, the powder preparation route is also quite complicated, for example, several times calcinations and subsequent physical grindings. Moreover, its electrochemical properties are greatly dependent on its crystalline particle size [16].

There are a few reports concerning nanometer zinc oxides synthesized by detonation of emulsion explosives, which is a kind of promising technique for synthesis of transition metal oxides. Here, for the first time, zinc oxides were synthesized from $Zn(NO_3)_2 \cdot 6H_2O$ by using detonation reaction by adding $LiNO_3$. The final emulsion explosive mixtures were prepared by mixing the emulsion matrices with epispastic polystyrene (EPS) micro-spheres.

2. Experimental

The emulsions were prepared using a simple facility consisting of a thermostat and a container equipped with a stirrer. The solution of oxidizers was heated to 105 °C and then slowly added to the container, in which a preheated (90 °C)

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mixture of fuels(oil and paraffin) with the emulsifier was agitated with the stirrer at a speed of 800 rpm. After adding the entire amount of the oxidizer, the agitation was continued for about 3 min to obtain fine particles of the emulsion matrices.

When the mass fraction of EPS is 2%, the detonation reaction equation is as follows.

$$
\begin{aligned}
&1.34LiNO_3 + 1.47Zn(NO_3)_2 \cdot 6H_2O + 4.90NH_4NO_3 \\
&\quad + 0.05C_{24}H_{44}O_6 + 0.15C_{18}H_{38} + 0.19C_8H_8 \rightarrow 0.67Li_2O \\
&\quad + 1.47ZnO + 5.42CO_2 + 7.04N_2 + 23.33H_2O + 0.18O_2
\end{aligned}
$$

11.96% of the initial emulsion explosive converts to ZnO.

The explosive charges were put into a thin plastic bag with an approximately 920 kg/m^3 density and the mass was fixed at 0.800 kg of explosive matter. For each charge an electric no. 8 initiator and a 0.038 kg plastic RDX (Hexogen or Cyclotrimethylene trinitramine) booster were used. The detonation experiments were performed in an explosive chamber (shown in Fig. 1). This method provides a very fast quenching space. The air surrounding the charge provides efficient cooling of detonation products and thus reduces the reuniting of obtained nanoparticles. The detonation experiments were done in a steel tank of 14.1 m^3. The explosive charge was placed in a polyethylene bag, which was suspended at the tank center. The detonation products contained some impurities such as fragments from the tank walls (Fe_2O_3, Al_2O_3), copper and steel from the detonator, and PE from the bag and the leg wires of the detonator. Large size impurities were eliminated by a simple filtration of the detonation products. The detonation products were washed thoroughly and dried. All the final products were analyzed by XRD (X-ray diffractometry) [$\lambda_{CuK\alpha} = 1.5418$] in the range of 10–80° (2θ). So for all the experiments, the detonation of emulsion explosives synthesized a black powder containing mainly ultradispersed zinc oxide.

The detonation products were then studied by use of XRD. XRD analysis was carried out on an XRD-6000 Shimadzu diffractometer using Cu Kα irradiation. The diffraction intensities were measured every 0.028° step for 1 s in the 2θ range from 10° to 80° at room temperature (293 K). The shape and size of the as-obtained particles were observed by transmission electron microscope (TEM, Tecnai G^2 20 S-twin).

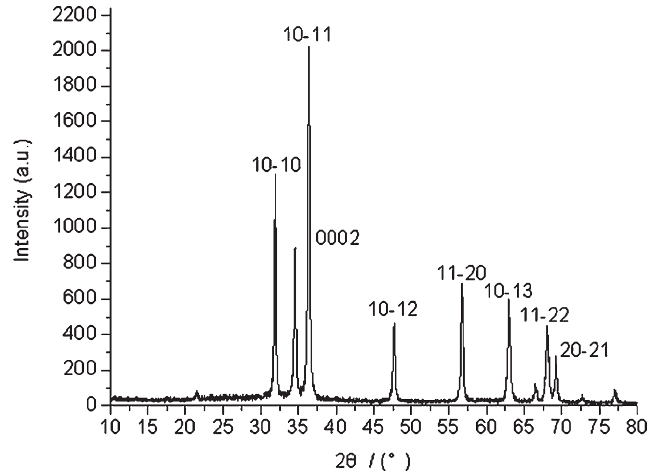

Fig. 2. XRD pattern of the as-prepared zinc oxides.

3. Results and discussion

A distinguishing feature of emulsion explosives is that in the aqueous solution, the lithium nitrate, zinc nitrate and ammonium nitrate are present in the form of tiny droplets covered with a very thin fuel layer. As a result, the interfacial surface of the emulsion is very large; the unconventional emulsion explosive in a lower density can be detonated completely when initiated with a booster.

The addition of metal nitrates to emulsion compositions deteriorates the detonation properties of explosives containing only ammonium nitrate. The decrease in performance is most considerable in the initial stage of expansion of detonation products. With increase in the volume of detonation products, these discrepancies decrease. This implies that chemical reactions also proceed in expanding detonation products and additional energy released in these reactions is converted to mechanical

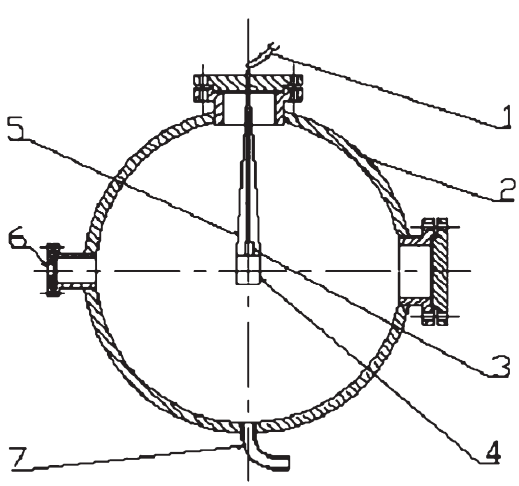

Fig. 1. Schematic of the explosive chamber. 1—Power line; 2—explosion chamber; 3—detonator; 4—explosive; 5—lifting rope; 6—exhausting hole; 7—deslagging pipe.

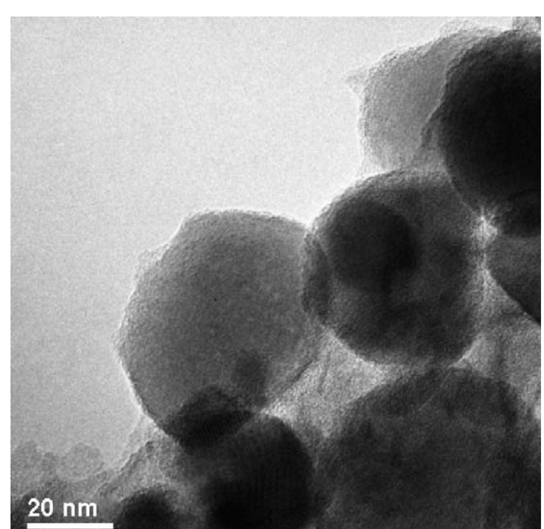

Fig. 3. HRTEM image of the as-prepared zinc oxides.