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Properties of ZnO and Zn Nanoparticles Produced by Electrical Discharge in Liquid Method

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Abstract: *The physical processes used to synthesize nanoparticles today are labor-intensive and inefficient in terms of energy use. Our approach, which we employed to create nanoparticles, is straightforward and economical. Using this technique, we synthesized Zinc Oxide (ZnO) nanoparticles and investigated their characteristics using several characterization techniques. We can regulate the form and size of our nanoparticles by altering the experimental conditions, as demonstrated by our investigations. This demonstrates the importance of experimental parameters in synthesizing ZnO nanoparticles by this method. This approach produced ZnO nanoparticles that were smaller than those described in the literature and had a blue shift, as a result, greater band gap energy. Using this technique, we improved process productivity while controlling the shape of our ZnO nanoparticles.*

Keywords: Electric discharge; Nanoparticles; Synthesis; Zinc Oxide

8. INTRODUCTION

Due to their widespread use in practically all research and development fields, nanoparticles are currently enjoying very high levels of popularity [1, 2]. Zinc Oxide (ZnO) nanoparticles stand out among them due to their distinct electrical and optical characteristics. These characteristics have allowed them to find significant practical uses in a variety of sectors, including cosmetics, functional devices, and catalytic reactions [3]. As a result, it is crucial that the production of these nanoparticles be an easy and affordable process.

Today, a variety of physical, chemical, and biological techniques are used to synthesize ZnO nanoparticles [4]. The arc discharge is one of the more affordable and straightforward physical processes that has been used to create various metal particles and carbon nanomaterials [5-7]. However, this technique generates continuous plasma, which results in the creation of large-sized nanoparticles. Additionally, this approach uses a lot of electrical energy because the liquid evaporates quickly.

This study aims to synthesize ZnO nanoparticles using a quick and inexpensive method based on electrical discharge between two metal electrodes dipped in a dielectric liquid [8] and examine how the experimental parameters affect the nanoparticles that are produced. This approach enables the synthesis of different metal nanoparticles and the control of their configurations by altering the experimental conditions [9]. It is straightforward, adaptable, and inexpensive.

9. MATERIALS AND METHOD

In this work, ZnO nanoparticles were synthesized using electrical discharge equipment that we built in our lab. A schematic illustration of the equipment is shown in Figure 1. Kojundo Co., Rare Metallic Co. provided the employed Zn electrode (99.9% pure) and the surfactant substance CTAB (Cetrimonium bromide [$(C_{16}H_{33})N(CH_3)_3Br$)]. 95 percent ethanol ($C_2H_5OH$) and distilled water served as the dielectric fluid.

Zn rods, measuring approximately 5 mm in diameter and 12 mm in length, were first placed in the device and immersed in the dielectric liquid to begin the experiment. The vibrator was then turned on to permit continual electrode vibrations during the experiment. After that, the device was powered up, causing an electric discharge to be induced in the space between the electrodes filled with the surrounding liquid to synthesize ZnO nanoparticles. Four distinct experiments were carried out with various dielectric liquids, each lasting an hour (Table 1). Following the synthesis, the precipitated nanoparticles were taken out of the liquid, repeatedly rinsed with distilled water and 95 percent ethanol, and then desiccated at room temperature to obtain the final power of nanoparticles. Then they were sent for further investigations of their properties.

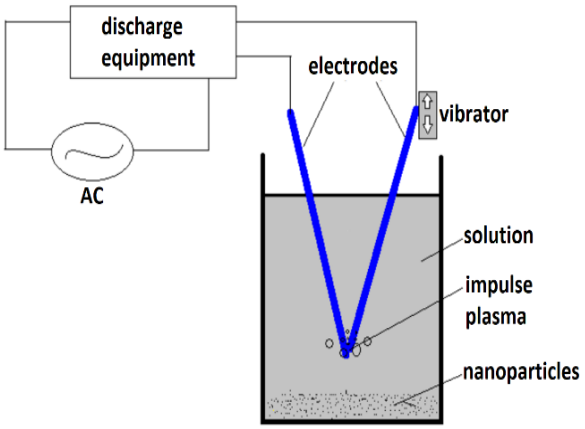

Fig. 1. Schematic illustration of the equipment.

By using X-ray diffraction analysis (XRD), the phase compositions of the final products produced in our work were determined. At Kumamoto University in Japan, the XRD patterns were recorded using a RINT-2500 HV diffractometer with a copper Cu Kα radiation wavelength of 0.15406 nm and an X-Ray of 40kV/200mA. ZnO nanocomposite sample shape and dispersion were examined using scanning electron microscopy. At Kumamoto University in Japan, a JEOL JSM-7600F was used to capture images of the products using a field emission scanning electron microscope (FE-SEM). At Kyrgyz-Turkish Manas University, UV-Visible analyses were used and carried out utilizing UV-Visible spectroscopy to investigate the optical properties of our materials.

Table 1. Four different experimental conditions.

	1st experiment (a)	2nd experiment (b)	3rd experiment (c)	4th experiment (d)
Dielectric liquid	Distilled water	Distilled water + 0.004 gr CTAB	Ethanol 95% (C_2H_5OH)	Ethanol 95% (C_2H_5OH) + 0.004 gr CTAB
Dielectric liquid amount	100 ml	100 ml	100 ml	100 ml
Experiment time	1 hour	1 hour	1 hour	1 hour
Amount of the final powder product	0.717 gr	0.406 gr	0.738 gr	0.313 gr

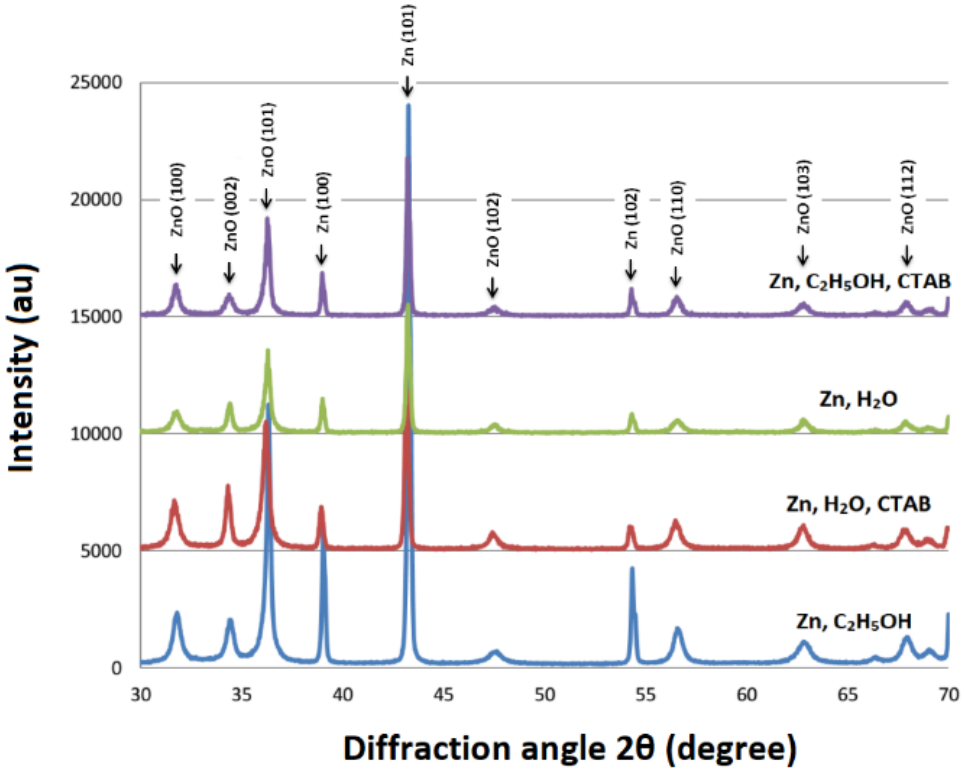

Fig. 3. XRD patterns of the nanoparticles synthesized by electrical discharge in liquid.

Table 2. Cell parameters calculated using XRD data for nanoparticles synthesized by electrical discharge in liquid.

	Standart	Sample 1 (Distilled water) (a)	Sample 2 (Distilled water + CTAB) (b)	Sample 3 (Ethanol) (c)	Sample 4 (Ethanol + CTAB) (d)
Cell parameters (Å)	a= 3.24967 c= 5.20660	a= 3.24628 c= 5.20634	a=3.26032 c= 5.22098	a=3.25031 c=5.21215	a=3.24621 c=5.20916
Cell volume (Å^3)	V= 47.61715	V= 47.51547	V= 48.06414	V= 47.68668	V= 47.53916
Change in the volume from the standard (%)	-	-0.21	+0.94	+0.15	-0.16
Phases percentage (%)	-	35.7 % - Zn 64.3 % - ZnO	27.8 % - Zn 72.2 % - ZnO	36.0 % - Zn 64.0 % - ZnO	45.3 % - Zn 54.7 % - ZnO

10. RESULTS AND DISCUSSION

The four experiments each lasted one hour, and the applied pulse current peak was about 100 A (Fig. 2). Despite the similar time and the applied current, the final powder achieved in each experiment varied. The resulting powder was less when surfactant agent CTAB was introduced to the dielectric liquid than it was in the studies without the surfactant agent (Table 1). It is because of the surfactant ingredient increased the liquid's electrical conductivity, which led to a reduction in the

discharge between the electrodes and lower productivity. Additionally, because ethanol has a higher resistance than water, the discharge between the electrodes is enhanced, increasing productivity. However, it's likely that when we introduced CTAB to ethanol, it disintegrated in the alcohol and increased the impurity, which decreased productivity.

Table 2 displays the outcomes of refinement. Our final powder is made up of two phases, Zn and ZnO nanoparticles, according to the results. However, in all experiments, ZnO nanoparticles were formed in the majority. The percentages of ZnO nanoparticles in the samples were nearly the same in distilled water and ethanol without a surfactant agent, 35.7 % Zn, 64.3 % ZnO, and 36.0 % Zn, 64.0 % ZnO respectively. The number of produced ZnO nanoparticles in distilled water rose with adding CTAB, 27.8 % Zn, 72.2 % ZnO, while it decreased in ethanol with the presence of the surfactant agent CTAB, 45.3 % Zn, 54.7 % ZnO. As was already indicated, one cause for this might be the surfactant ingredient dissolving in the alcohol and producing contaminants in the liquid. But to fully explain it, more research is necessary. The number of synthesized nanoparticles in the distilled water was less than the recommended amounts. The cause of this may be that the nanoparticles can be frozen until completely developed in relatively cold water (at room temperature). Cell parameters of our nanoparticles synthesized in distilled water and ethanol were almost the sample as standard with very small changes in volume, 47.51547 $Å^3$ in water and 47.68668 $Å^3$ in ethanol whereas the standard is 47.61715 $Å^3$. However, we anticipated that the volume would increase up to 48.06414 $Å^3$ when we added the surfactant ingredient CTAB to distilled water. On the other hand, the volume of the nanoparticles was reduced to 47.53916 $Å^3$ when surfactant agent CTAB was added to ethanol, and one of the potential causes of this could be the above-mentioned contaminant.

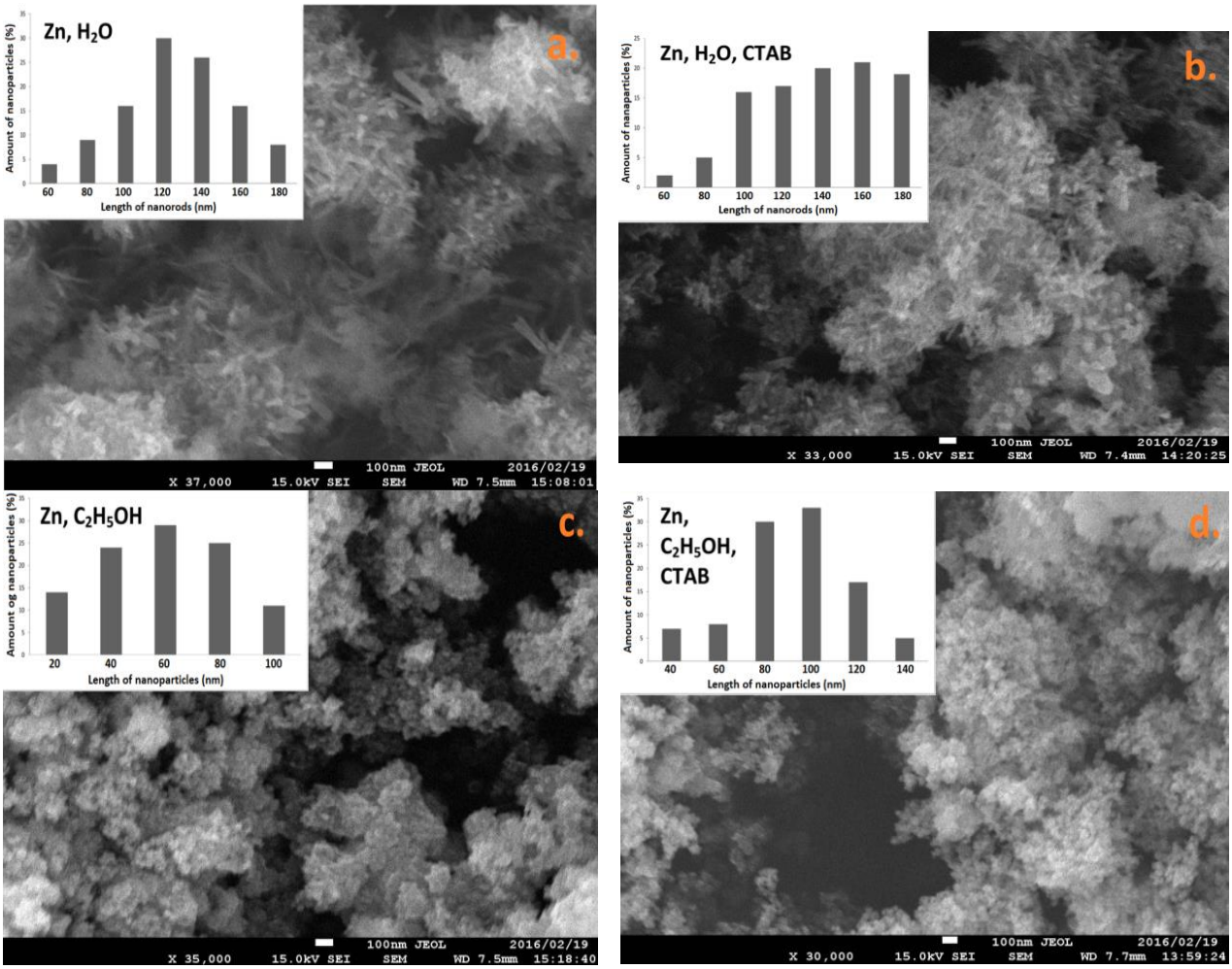

Fig. 4. SEM images of nanoparticles obtained from the four experiments. The insets of each image show the size distribution of each sample determined by using Image-J. a) in distilled water, b) CTAB added to distilled water, c) ethanol, d) CTAB added to ethanol.

SEM pictures of the nanoparticles produced by four trials are shown in Figure 4. Synthesized nanoparticles were seen to be nano-sticks or nanorods in distilled water (Figure 4a). The hexagonal nanoparticles that are synthesized begin to develop on one or both of their opposing sides, which results in the formation of nanorods. These nanorods had diameters of 30 to 60 nm and lengths that were typically between 120 and 130 nm. Once more nanorods were synthesized (Figure 4b) when the surfactant agent CTAB was added to the water, but this time they were thicker and longer. Most nanorods were greater than 100 nm in length, with an average of 155–165 nm and a diameter of 20–30 nm. Our nanoparticles were found to be spherically formed in

ethanol (Figure 4c), with an average diameter of 55–60 nm. The hexagonal shape begins to develop on all sides, which causes the nanoparticles to take on a flower-like shape. However, because of their tiny sizes, these flower-shaped nanoparticles can appear as spherical shapes in photographs [8]. The surfactant agent was added to the alcohol, which resulted in the production of spherically shaped nanoparticles once more, this time with slightly bigger sizes; their average diameter was between 80 and 100 nm (Figure 4d).

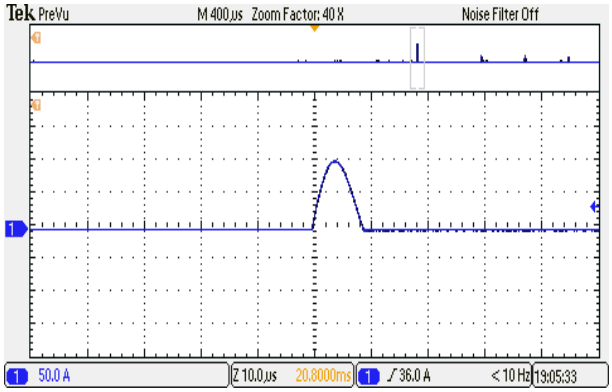

Fig. 2. The wavelength of applied current.

Figure 3 displays the four samples' XRD patterns. According to JCPDS (Joint Committee on Powder Diffraction Standards) card number No. 65-3411, which revealed our sample had a hexagonal structure, phase compositions of the samples were identified.

Investigating the UV-Visible spectra of our materials, which are shown in Figure 5 and Table 3, allowed us to learn about their optical properties. Figure 6 shows bandgap energies driven by UV-Visible analysis for each experiment. Our nanoparticles had absorption wavelengths that were comparatively smaller than those stated in earlier works [10,11]. Additionally, bandgaps were greater than standard. This might be due to the fact that our nanoparticles were different from theirs in terms of cell volumes and sizes. Additionally, when CTAB was added to a liquid to synthesize nanoparticles, the resultant particles were larger than those produced in water and ethanol and had shorter adsorption wavelengths and larger band gaps. This is also in accordance with the literature and theory that predicts that when nanoparticle sizes increase, their adsorption wavelengths would shorten, and their band gaps will widen [12–14].

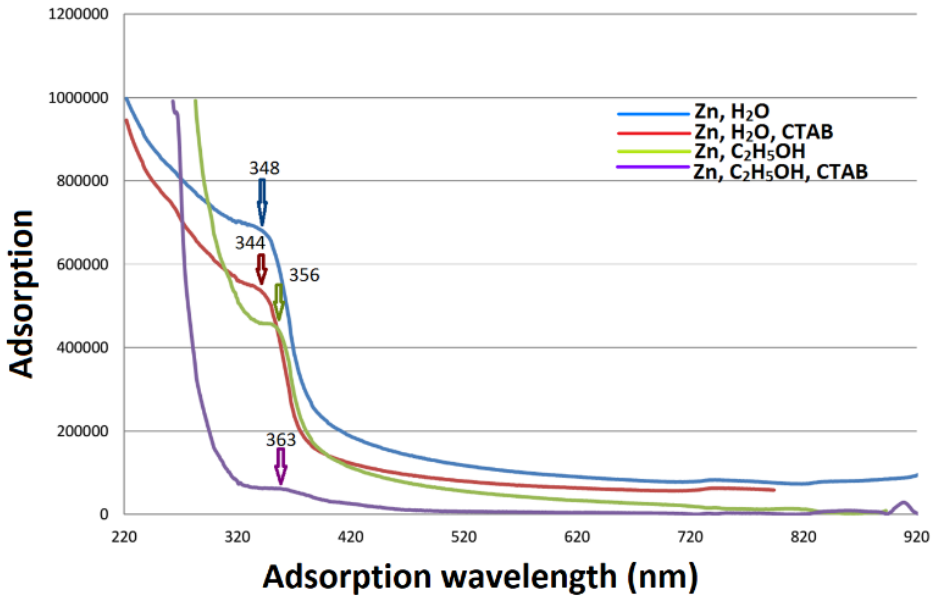

Fig. 5. The UV-Visible spectrum of the nanoparticles synthesized from the four experiments.

Table 3. Adsorption wavelengths and bandgaps of the samples.

Sample	Adsorption wavelength (nm)
Zn, H_2O	348
Zn, H_2O, CTAB	344
Zn, C_2H_5OH	356
Zn,C_2H_5OH, CTAB	363

11. CONCLUSION

Using a straightforward and affordable approach called electrical discharge in a liquid, we synthesized ZnO nanoparticles for this study and looked at their properties. In our tests, not only ZnO nanoparticles but also Zn nanoparticles were synthesized, according to XRD measurements. However, by altering the experimental circumstances, the phase composition of the final products can be regulated and minimized. We can observe from SEM photos that by altering the experimental setup and/or including a surfactant agent, we can modify the form of our nanoparticles and stimulate their growth. Our nanoparticles would have shorter adsorption wavelengths and greater band gap energies, according to the UV-Visible studies. This suggests that the ZnO nanoparticles made using our technology can be used in recently created devices like diodes and other functional ones.

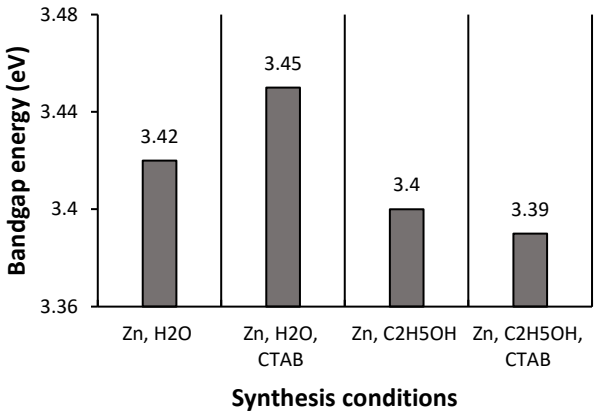

Fig. 6. Bandgap energies of synthesized samples.

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