Research Article

The Synthesis and Physical Properties of Magnesium Borate Mineral of Admontite Synthesized from Sodium Borates

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Received 17 April 2014; Revised 16 July 2014; Accepted 18 July 2014; Published 13 August 2014

Academic Editor: You Song

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Magnesium borates are significant compounds due to their advanced mechanical and thermal durability properties. This group of minerals can be used in ceramic industry, in detergent industry, and as neutron shielding material, phosphor of thermoluminescence by dint of their extraordinary specialties. In the present study, the synthesis of magnesium borate via hydrothermal method from sodium borates and physical properties of synthesized magnesium borate minerals were investigated. The characterization of the products was carried out by X-ray diffraction (XRD), Fourier transform infrared (FT-IR) and Raman spectroscopies, and differential thermal analysis and thermal gravimetry (DTA/TG). The surface morphology was examined by scanning electron microscopy (SEM). B_2O_3 content was determined through titration. The electrical resistivity/conductivity properties of products were measured by Picoammeter Voltage Source. UV-vis spectrometer was used to investigate optical absorption characteristics of synthesized minerals in the range 200–1000 nm at room temperature. XRD results identified the synthesized borate minerals as admontite $[MgO(B_2O_3)_3 \cdot 7(H_2O)]$ with code number “01-076-0540” and mcallisterite $[Mg_2(B_6O_7(OH)_6)_2 \cdot 9(H_2O)]$ with code number “01-070-1902.” The FT-IR and Raman spectra of the obtained samples were similar with characteristic magnesium borate bands. The investigation of the SEM images remarked that both nano- and microscale minerals were produced. The reaction yields were between 75.1 and 98.7%.

1. Introduction

Magnesium borates are considerable borate minerals by virtue of their high heat resistance, light weight, high elasticity coefficient, birefringent crystal structure, anticorrosion, and antiwear properties [1–4]. Owing to these properties, magnesium borates have extensive usage area and application potentials. Magnesium borates can be used in ceramic industry, in superconducted material production, in detergent composition, in friction reducing additive manufacture, in fluorescent discharge lamps as luminescent material, in ferroelastic material production, in cathode ray tube screens, in X-ray screens, and as thermoluminescent phosphor [5–10]. And also magnesium borates have great potential in areas of

electronic ceramics reinforcement, semiconductor material synthesis, and plastics or aluminum/magnesium matrix alloy production [11, 12].

The production methods of magnesium borate minerals can be divided into two by hydrothermal and thermal methods [13]. In previous studies different types of magnesium borate minerals were synthesized. For the syntheses different starting materials were used. MgO and H_3BO_3 were used by Dou et al. [1] to synthesis magnesium borate types of $MgO \cdot 3B_2O_3 \cdot 7H_2O$ and $2MgO \cdot B_2O_3 \cdot H_2O$. Li et al. [2] prepared $Mg_2B_2O_5$ by the raw materials of $MgBr_2 \cdot 6H_2O$ and $NaBH_4$. Zhu et al. [14] used $MgCl_2 \cdot 6H_2O$, H_3BO_3 , and $NaOH$ to synthesize $MgBO_2(OH)$. $Mg(OH)_2$ and H_3BO_3 were used by Elssfah et al. [15] for the purpose of producing

$\text{Mg}_2\text{B}_2\text{O}_5$, MgO , B_2O_3 , and H_3BO_3 were selected as starting materials for synthesis of $\text{Mg}_2\text{B}_2\text{O}_5$ by Li et al. [16]. Wang et al. [17] used $\text{MgNO}_3 \cdot 6\text{H}_2\text{O}$ and $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ for obtaining magnesium borate nanowires. $2\text{MgO} \cdot 2\text{B}_2\text{O}_3 \cdot \text{MgCl}_2 \cdot 14\text{H}_2\text{O}$ and H_3BO_3 were chosen by Zhihong and Mancheng [18] for preparation of $2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$.

The specific type of magnesium borate mineral, namely, admontite, was synthesized from MgO and H_3BO_3 at 100°C for the reaction times of 120 and 240 minutes by Derun et al. [19]. Also at their other study, Derun and Senberber [20] synthesized pure mcallisterite by using the same raw materials of MgO and H_3BO_3 .

The common point to all previous magnesium borate syntheses by hydrothermal method was high reaction temperatures ($\geq 100^\circ\text{C}$) and extended reaction times, where in literature hydrothermal syntheses are frequently driven in a temperature range of $100\text{--}220^\circ\text{C}$ [4]. Furthermore the crystallinities of the obtained minerals were not at the desired levels.

Considering different studies about preparation of magnesium borate in this study, in order to obtain the magnesium borates below 100°C reaction temperature and 120 minutes of reaction time, different combinations and mole ratios of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, H_3BO_3 , B_2O_3 , $\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$, and $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ were used as raw materials in the hydrothermal synthesis. The mole ratios of raw materials were decided from previous experiments [21]. The main originality of the study is to produce magnesium borate compounds at lower temperatures and shorter reaction times, which leads to less energy consumption and time for a green chemistry approach. Another novelty of this study is the investigation and comparison of the electrical and optical characteristics of bulk and nanowires magnesium borate crystal that were investigated in the literature [16, 22, 23]. The bulk magnesium borate crystal has a wide optical band gap of 5.44 eV according to theoretical calculation [22].

Synthesized magnesium borate minerals were characterized by using X-ray diffraction (XRD), Fourier transform infrared (FT-IR) spectroscopy, Raman spectroscopy, scanning electron microscopy (SEM), and differential thermal analysis and thermal gravimetry (DTA/TG). Electrical and optical properties of the different magnesium borate minerals were investigated with picoammeter voltage source and UV-vis spectrometer techniques, respectively.

2. Materials and Methods

2.1. Preparation and Characterization of the Raw Materials. Magnesium chloride hexahydrate ($\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$) was obtained from Merck Chemicals at minimum purity of 98% and particle size below $70\text{ }\mu\text{m}$. Other reactants were retrieved from Bandırma Boron Works with a particle size below 1 mm. Among these raw materials boric acid (H_3BO_3), tinalconite ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$), and borax ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$) have a minimum purity of 99.9% and boron oxide (B_2O_3) has a minimum purity of 98%. Since the $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ particle size was fine it was not pretreated, but other raw materials were processed by crushing, grinding through agate mortar (Retsch RM200), and sieving through Fritsch shaker sieve

to reduce particle size down to below $70\text{ }\mu\text{m}$. Then reactants were identified in Philips PANalytical XRD (step: 0.030° , time for step: 0.50 s, scan speed: $0.006^\circ/\text{s}$, and range: $7\text{--}90^\circ$) at 45 kV and 40 mA through the X-rays obtained in the Cu-K α tube.

2.2. Magnesium Borate Synthesis. Some preliminary analyses were carried out using different molar ratios of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O} : \text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O} : \text{H}_3\text{BO}_3$ (Mc:T:H) and the use of a molar Mc:T:H ratio of 1:1:3 throughout the analysis was selected for further experiments [19]. The expected reaction schemes are shown in (1)–(4):

The distilled water used in the experiments was obtained from a “Human Power I+” water treatment system and had a conductivity value of $18.3\text{ m}\Omega\text{-cm}$. The reaction temperatures and reaction times were selected between $60\text{--}100^\circ\text{C}$ and 30–240 min. The experiments were carried out in a glass reactor and the reaction temperature was set as constant by a temperature control unit.

At the end of the selected reaction times the solution was put in an incubator maintained at 40°C until the excess water evaporated and magnesium borate minerals were crystallized. Then crystallized magnesium borate minerals were washed with pure (96%) ethanol three times to separate unreacted components and byproduct of NaCl. Washed samples were dried in an incubator maintained at 40°C again. The experimental method was shown in Figure 1.

2.3. Magnesium Borate Characterization Studies. Synthesized magnesium borates were subjected to XRD, FT-IR spectroscopy, and Raman spectroscopy. The parameters used in XRD were the same as those used in Section 2.1; only the range of the patterns was set between 7 and 60° , since the characteristic peaks of magnesium borates are seen in that range.

FIGURE 1: Schematic experimental method.

The characteristic peaks of borate compounds were given in the range of $1500\text{--}500\text{ cm}^{-1}$ [24] so the spectrum ranges in FT-IR and Raman were selected as $1800\text{ cm}^{-1}\text{--}650\text{ cm}^{-1}$ and $1800\text{ cm}^{-1}\text{--}250\text{ cm}^{-1}$, respectively. Also no peak above 1800 cm^{-1} was observed in either one of the spectral analyses.

The morphological features of materials, including their structure, morphology, phase, shape, size, and distribution, are affected by their physical and chemical properties [25]. CamScan Apollo 300 Field-Emission SEM was used to observe the surface textures and particle sizes of the synthesized magnesium borate minerals at 20 kV. The detector used was back scattering electron (BEI) and the magnification was set to 10000.

The commercial values of the boron minerals are evaluated from the B_2O_3 content of these minerals. This analysis was carried out using the method reported by Derun et al. [19].

Thermal analysis of a pure admontite selected from the XRD results was studied between the temperature range of $20\text{--}720^\circ\text{C}$ with a Perkin Elmer Diamond DTA/TG with a heating rate of $10^\circ\text{C}/\text{min}$ in an inert (nitrogen) atmosphere.

In order to investigate and characterize the product obtained after the thermal analysis, admontite mineral was placed in a Protherm MOS 180/4 high temperature furnace with $10^\circ\text{C}/\text{min}$ temperature increment to a maximum temperature of 720°C in nitrogen flowing ($5\text{ mL}/\text{min}$) atmosphere. After the thermal conversion, the product was analyzed by XRD with the same parameters given in Section 2.3.

Yield analysis was also carried out using the method reported by Derun et al. [19] where $\text{MgCl}_2\cdot 6\text{H}_2\text{O}$ was identified as the key component. Experiments were carried out in triplicate in three pure admontite minerals, which have the highest XRD scores in order to calculate the average yields and the standard deviations. The yield calculation of the biphasic samples was carried out based on the phase with the highest molecular weight.

The number of moles of product at the final stage, N_D , was divided by the number of consumed moles of the key reactant A to calculate the overall yield, Y_D (5). The number of moles of A that was consumed was calculated using the initial (N_{A0}) and the final (N_A) moles of the reactant. The equation then becomes as follows for a batch system [19, 26]:

$$Y_D = \frac{N_D}{N_{A0} + N_A}. \quad (5)$$

2.4. Electrical and Optical Properties of Magnesium Borates.

The synthesized magnesium borate compounds were pressed under pressure of 30 MPa into pellets with 13 mm diameters and 0.4 mm thickness. Electrical resistivity measurement of synthesized magnesium borate compounds which are coded with “Mc-Bx-B-60-240,” “Mc-T-B-80-60,” and “Mc-Bx-H-100-60” was carried out by standard current voltage measurement at room temperature using Keithley 6487 in dark with thermally evaporated silver contacts on both surfaces of pellets. The optical absorbance spectrum of magnesium

TABLE 1: XRD scores of the synthesized magnesium borate minerals.

Reaction temperature (°C)	Reaction time (min)	Mc-T-H*		Mc-T-B*		Mc-Bx-H*		Mc-Bx-B*	
		Admontite	Mcallisterite	Admontite	Mcallisterite	Admontite	Mcallisterite	Admontite	Mcallisterite
60	30	68	64	59	64	67	—	60	—
	60	62	68	66	52	68	—	63	—
	120	65	35	59	58	64	46	68	—
	240	67	55	61	48	63	—	71	—
80	30	61	76	66	40	64	—	65	—
	60	65	54	70	—	65	—	64	56
	120	56	54	62	56	57	—	60	—
	240	49	60	63	45	65	—	65	—
100	30	45	80	47	79	63	—	62	—
	60	46	79	49	81	70	—	58	31
	120	44	80	39	81	56	44	61	40
	240	49	74	48	60	62	—	64	17

*Mc: $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, T: $\text{Na}_2\text{B}_4\text{O}_5(\text{OH})_4 \cdot 3\text{H}_2\text{O}$, H: H_3BO_3 , B: B_2O_3 , and Bx: $\text{Na}_2\text{B}_4\text{O}_5(\text{OH})_4 \cdot 8\text{H}_2\text{O}$.

borate compounds was taken by Perkin Elmer UV-vis spectrophotometer at room temperature. In this measurement the magnesium borate compounds were dispersed in HCl solution in quartz tube (1 cm × 1 cm).

3. Results

3.1. Results of the Raw Material Characterization. Magnesium source of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ was determined as “bischofite” (reference code: 01-077-1268). Sodium-boron source of $\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$ was determined as “tincalconite” (reference code: 01-079-1529) and another sodium-boron source of $\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$ was found as the mixture of both “borax” (reference code: 01-075-1078) and “tincalconite” (reference code: 01-079-1529). Boron sources of H_3BO_3 were determined as “sassolite” (reference code: 01-073-2158) and B_2O_3 was determined as the mixture of two types of “boron oxide” (reference codes: 00-006-0297 and 01-088-2485).

3.2. XRD Results of the Synthesized Magnesium Borates. Synthesized minerals XRD results were given in Table 1. It is seen from the results that the synthesized products were admontite [$\text{MgO}(\text{B}_2\text{O}_3)_3 \cdot 7(\text{H}_2\text{O})$] and mcallisterite [$\text{Mg}_2(\text{B}_6\text{O}_7(\text{OH})_6)_2 \cdot 9(\text{H}_2\text{O})$]. The XRD patterns of three pure admontite minerals, which have the highest XRD scores, were represented in Figure 2.

As it is seen from Figure 2, the five major characteristic peaks of admontite mineral are seen at all three minerals at around 7°, 17°, 23°, 29°, and 34°. The crystallographic data of synthesized magnesium borates are given in Table 2.

The obtained products for Mc-T-H experimental setup were formed in two distinct phases at all reaction temperatures and times. The higher mcallisterite scores were reached at increasing reaction temperatures. For Mc-T-B experimental setup, the obtained products were formed in two distinct phases the same as Mc-T-H set of experiment at all reaction temperatures and times except at 80°C and

FIGURE 2: XRD patterns of pure admontite minerals.

for the reaction time of 60 minutes. The pure admontite which had the highest crystal score was synthesized at 80°C after 60 minutes. Most of the synthesized minerals were pure admontite for Mc-Bx-H experimental setup apart from synthesis at 60°C and 100°C when the reaction time was 120 minutes. The highest admontite crystal score was achieved at 100°C after 60 minutes. At Mc-Bx-B experimental setup, for all reaction times, the obtained minerals which were produced at 60°C were pure admontite. Also, the highest admontite crystal score for all experimental setups was reached after the reaction of 240 minutes at 60°C.

3.3. FT-IR and Raman Spectral Analysis Results for the Synthesized Products. The FT-IR and Raman spectra of the synthesized magnesium borate minerals were very similar

TABLE 2: Crystallographic data of synthesized magnesium borates.

Mineral name	Admontite	Mcallisterite
Pdf number	01-076-0540	01-070-1902
Chemical formula	$\text{MgO}(\text{B}_2\text{O}_3)_3 \cdot 7(\text{H}_2\text{O})$	$\text{Mg}_2(\text{B}_6\text{O}_7(\text{OH})_6)_2 \cdot 9(\text{H}_2\text{O})$
Molecular weight (g/mole)	375.27	768.56
Crystal system	Monoclinic	Rhombohedral
Space group	P21/c (number 14)	Pr3c (number 167)
a (Å)	12.6610	11.5490
b (Å)	10.0910	11.5490
c (Å)	11.3220	35.5670
α (°)	90.00	90.00
β (°)	109.60	90.00
γ (°)	90.00	120.00
z	4.00	6.00
Density (calculated) ($\text{g}\cdot\text{cm}^{-3}$)	1.83	1.86

FIGURE 3: FT-IR spectra of pure admontite minerals.

and were also in accordance with Yongzhong et al. [24]. FT-IR and Raman spectra of pure admontite minerals are given in Figures 3 and 4, respectively.

In the FT-IR spectrum, asymmetric stretching of the three-coordinate boron [$\nu_{\text{as}}(\text{B}_{(3)}\text{-O})$] was observed in the range of 1419 cm^{-1} – 1344 cm^{-1} . The peak at between 1229 cm^{-1} and 1225 cm^{-1} corresponded to bending of B-O-H [$\delta(\text{B-O-H})$] and the asymmetric stretching of the four-coordinate boron [$\nu_{\text{as}}(\text{B}_{(4)}\text{-O})$] was observed in the range of 1084 cm^{-1} – 999 cm^{-1} . Between the range of 953 cm^{-1} and 897 cm^{-1} symmetric stretching of the three-coordinate boron [$\nu_{\text{s}}(\text{B}_{(3)}\text{-O})$] was observed. The peaks between 856 cm^{-1} and 805 cm^{-1} coincided with symmetric stretching of the four-coordinate boron [$\nu_{\text{s}}(\text{B}_{(4)}\text{-O})$]. Bending of three-coordinate boron [$\delta(\text{B}_{(3)}\text{-O})$] was observed at around 671 cm^{-1} .

FIGURE 4: Raman spectra of pure admontite minerals.

In the Raman spectrum, the band in the region of 952 cm^{-1} was asymmetric stretching of the four-coordinate boron [$\nu_{\text{as}}(\text{B}_{(4)}\text{-O})$]; the bands at around 636 cm^{-1} – 635 cm^{-1} were associated with $\nu_p[\text{B}_6\text{O}_7(\text{OH})_6]^{2-}/\nu_p[\text{B}_3\text{O}_3(\text{OH})_4]^-$. The peaks at and below 426 cm^{-1} belonged to bending of four-coordinate boron [$\delta(\text{B}_{(4)}\text{-O})$].

3.4. B_2O_3 Content of the Synthesized Minerals. The B_2O_3 analysis results of the synthesized magnesium borate minerals are given in Table 3. The B_2O_3 content was calculated between 40.00% and 55.39%. In the synthesized pure admontite minerals of coded “Mc-Bx-B-60-240,” “Mc-T-B-80-60,” and “Mc-Bx-H-100-60,” B_2O_3 contents were found as $52.03 \pm 1.59\%$, $54.04 \pm 1.37\%$, and $51.92 \pm 2.28\%$, respectively. Since B_2O_3 content of the admontite mineral is 55.66% [19], the results were close to the literature value.

3.5. Surface Morphology and Particle Size of the Synthesized Admontite. Since the pure admontite minerals XRD scores were very close to each other (Mc-Bx-B-60-240: 71, Mc-T-B-80-60: 70, and Mc-Bx-B-100-60: 70), only “Mc-T-B-80-60” and “Mc-Bx-B-100-60” had been subjected to SEM analyses because of the low reaction times. SEM surface morphology and the particle size of admontite were given in Figure 5.

Obtained admontite crystals were layered, agglomerated, locally porous, smooth edged in “Mc-T-B-80-60,” and sharp edged in “Mc-Bx-B-100-60.” The size distribution, though varying due to the agglomerated structure, of admontite, of which “Mc-T-B-80-60” and “Mc-Bx-B-100-60” coded minerals particle sizes, was found between $2.04\text{ }\mu\text{m}$ – 283.74 nm and $2.38\text{ }\mu\text{m}$ – 207.10 nm , respectively.

3.6. Thermal Analysis Results. TG and DTG analyses of a selected (moderate reaction temperature and low reaction time) admontite which has a code of “Mc-T-B-80-60” are shown in Figure 6.

The analysis showed that three endothermic peaks occurred. The first peak that occurred between the temperatures of 40 and 59.47°C was the moisture. So admontite lost its crystal water via a two-step process, where in the first

TABLE 3: B₂O₃ contents of the synthesized magnesium borate minerals.

Reaction temperature (°C)	Reaction time (min)	B ₂ O ₃ (%)			
		Mc-T-H	Mc-T-B	Mc-Bx-H	Mc-Bx-B
60	30	51.21 ± 1.87	44.59 ± 1.75	45.73 ± 2.73	43.48 ± 2.28
	60	55.39 ± 1.37	53.33 ± 0.79	45.89 ± 2.51	49.92 ± 2.28
	120	52.54 ± 0.67	51.65 ± 0.50	45.09 ± 1.82	40.00 ± 1.64
	240	53.65 ± 2.16	41.87 ± 1.82	45.48 ± 2.83	52.03 ± 1.59
80	30	54.27 ± 1.59	50.27 ± 2.29	43.48 ± 2.28	46.86 ± 1.14
	60	43.48 ± 2.28	54.04 ± 1.37	45.26 ± 1.83	50.89 ± 0.91
	120	37.04 ± 2.28	54.42 ± 2.00	48.47 ± 1.14	44.87 ± 1.55
	240	43.48 ± 2.28	54.30 ± 0.67	46.83 ± 1.96	45.25 ± 1.59
100	30	53.92 ± 1.79	54.27 ± 2.04	43.48 ± 2.28	43.16 ± 1.37
	60	53.18 ± 0.42	54.01 ± 0.25	51.92 ± 2.28	41.97 ± 2.01
	120	54.24 ± 1.83	51.89 ± 1.08	50.40 ± 2.05	41.38 ± 1.59
	240	53.65 ± 2.16	49.92 ± 2.73	43.48 ± 2.28	40.04 ± 2.28

FIGURE 5: SEM surface morphology and the particle size of admontite minerals.

FIGURE 6: TG and DTG analyses of admontite mineral.

dehydration step the initial, peak, and final temperatures were seen as 59.47°C, 100.10°C, and 129.45°C. In the second step, initial, peak, and final temperatures were found as 129.45°C, 212.06°C, and 710.00°C. Weight decreases were 9.965% and 24.130% for the first and second steps, respectively. Total weight loss was calculated as 34.095%, which is close to theoretical structural water content (33.60%) of admontite

FIGURE 7: XRD pattern of MgB₄O₇.

mineral. So in the first dehydration step there was small moisture content of 0.495%. According to the found data the dehydration steps of appeared as, which is in a mutual agreement with the study of Derun et al. [19]:

3.7. Thermal Conversion Results of the Synthesized Magnesium Borates. According to thermal conversion results, the calcined magnesium borate lost 33.62% of its weight. This result

FIGURE 8: Reaction yields of synthesized admontite minerals.

conformed with the TG analyses and admontite's theoretical structural water content of 33.60%. XRD results showed that the admontite mineral lost all of its structural water and turned to a dehydrated magnesium borate mineral MgB_4O_7 (pdf 00-031-0787). Before XRD analysis, the calcined admontite was washed with pure ethanol and dried at 40°C to remove B_2O_3 which occurred together with MgB_4O_7 during the calcination. The weight changes before and after leaching showed the equimolar MgB_4O_7 and B_2O_3 conversion.

The crystallographic data obtained from XRD are presented in Table 4 for admontite and MgB_4O_7 . The XRD pattern of MgB_4O_7 is given in Figure 7.

At Figure 7 the five major characteristic peaks of MgB_4O_7 are seen at 17°, 20°, 22°, 26°, and 41°.

3.8. Yield Calculation of the Synthesized Magnesium Borates. Reaction yields increased with increasing reaction temperature and time for both sets which is shown in Figure 8. The yields were calculated between 76.2–95.2%, 75.1–92.6%, 82.8–97.2%, and 82.0–98.7% for the sets of “Mc-T-H,” “Mc-T-B,” “Mc-Bx-H,” and “Mc-Bx-B,” respectively.

The pure admontite minerals yields were found as 85.9 ± 0.9 , 85.0 ± 0.6 , and $94.0 \pm 1.0\%$ for the parameters of

TABLE 4: Crystallographic data of synthesized magnesium borates.

Mineral name	Magnesium borate
Pdf number	00-031-0787
Chemical formula	MgB_4O_7
Molecular weight (g/mole)	179.55
Crystal system	Orthorhombic
Space group	Pbca (number 61)
a (Å)	8.5960
b (Å)	13.7290
c (Å)	7.9560
α (°)	90.00
β (°)	90.00
γ (°)	90.00
z	8.00
Density (calculated) ($\text{g}\cdot\text{cm}^{-3}$)	2.54

FIGURE 9: The optical absorption spectra of admontite and calcined admontite.

“Mc-Bx-B-60-240,” “Mc-T-B-80-60,” and “Mc-Bx-H-100-60,” respectively.

3.9. Results of Electrical and Optical Measurements. The absorption spectra of the magnesium borate mineral of admontite were measured in the wavelength range of 200–1000 nm at room temperature. Figure 9 shows the optical absorption spectra of admontite and calcined admontite. The energy gap of the admontite and calcined admontite was determined from extrapolation of high energy part of absorption spectra as about 4.77 eV and 4.13 eV, respectively.

Figure 10 shows the current voltage characteristics of the different magnesium borate compounds, which are coded with “Mc-Bx-H-100-60,” “Mc-Bx-B-60-240,” “Mc-T-B-80-60,” and calcined admontite. The resistivity of the compounds is derived to be 3.07×10^7 , 1.09×10^7 , 1.18×10^8 , and $1.51 \times 10^7 \Omega\text{m}$, respectively, which are obtained from the

FIGURE 10: The current voltage characteristics of different magnesium borate compounds.

current voltage curves. The resistivities of the compounds were changed in the range of 10^7 – $10^8 \Omega\text{m}$.

4. Discussion and Conclusions

In this study for the approach of green chemistry the hydrothermal method at lower reaction temperature and reaction time is conducted in the synthesis of magnesium borates from sodium borates. From the results of this study, contrary to the previous studies, even at 60°C and 30-minute reaction time pure admontite synthesis was accomplished with high crystal scores. Derun et al. [19] reported the highest crystal score as 61 although in this study higher crystal scores were reached even when reducing reaction temperatures and furthermore the yield of obtained synthesized compounds ranged between 75.1 and 98.7%. FT-IR and Raman spectroscopy results showed that the products had characteristic peaks of magnesium borates in both infrared and visible regions. According to SEM results, the particle sizes of synthesized magnesium borate minerals were between 2.38 μm and 207.10 nm.

Also, the electrical conductivity of the magnesium borate compounds was determined in the range of 10^{-7} – $10^{-8} (\Omega\text{m})^{-1}$ with the content of pure admontite minerals yields in the range of 85–94%. Resistivity measurement of bulk magnesium borate has not been studied and conductivity of magnesium borate nanowires is calculated to be about $10^{-4} (\Omega\text{m})^{-1}$ in literature [16]; the wide difference in the conductivity of the magnesium borate obtained by Li et al. and the present study comes from the content of structural water inside the magnesium borates, where in this study $\text{MgO}(\text{B}_2\text{O}_3)_3 \cdot 7(\text{H}_2\text{O})$ type of magnesium borate is synthesized; on the contrary Li et al. synthesized $\text{Mg}_2\text{B}_2\text{O}_5$ which is a dehydrated type of magnesium borate.

The energy band gaps of admontite and calcined admontite were determined to be about 4.77 eV and 4.13 eV, respectively, where in literature Kumari et al. [3] calculated the energy band gap of magnesium borate to be 4.72 eV, which is in mutual agreement with the obtained energy gap values.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgment

This research has been supported by Yildiz Technical University Scientific Research Projects Coordination Department with Project number of 2013-07-01-GEP04.

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