Title	Study on Microstructural and Temperature Dependent Electrical Conductivity of Magnesium Ferrite, $MgFe_2O_4$
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Publication Type	Local publication
Publisher (Journal name, issue no., page no etc.)	Journal of the Myanmar Academy of Arts and Science (Jour. Myan. Acad. Arts & Sc. 2013 Vol. XI. No.2)
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Study on Microstructural and Temperature Dependent Electrical Conductivity of Magnesium Ferrite, $MgFe_2O_4$

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Abstract

Magnesium Ferrite, $MgFe_2O_4$, was prepared by solid state reaction method. Analar grade Magnesium Oxide, MgO and Ferric Oxide, Fe_2O_3 with stoichiometric composition were used to prepare the sample. Morphological features of the as-prepared sample were studied by Scanning Electron Microscope (SEM). SEM micrograph shows that the sample is circular shape with the grain sizes 0.10 μm – 0.50 μm and the samples are homogeneous. Temperature dependent electrical conductivities of the sample were investigated in the temperature range 300 K – 973 K. Experimental results show that the sample is a fast ion conductor in high temperatures.

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Introduction

During the last years, many kinds of ceramic oxides have been investigated actively as humidity sensing materials [1]. Humidity sensors based on semiconducting oxides have certain advantages compared to other types of humidity sensors, such as low cost, simple construction, small size and ease of placing the sensor in the operating environment. Basically, a ceramic sensor can detect humidity on the principle of measuring a change in the resistance by water vapor adsorption [2]. Spinel ferrites with the general formula AFe_2O_4 (A = Mn, Co, Ni, Mg, or Zn) are very important magnetic materials because of their interesting magnetic and electrical properties with chemical and thermal stabilities. Magnesium ferrite ($MgFe_2O_4$) is one of the most important ferrites. It has a cubic structure of normal spinel-type and is a soft magnetic *n*-type semiconducting material, which finds a number of applications in heterogeneous catalysis, sensors, non-resonant devices, radio frequency circuits, high quality filters, rod antennas, transformer cores, read/write heads for high-speed digital tapes and operating devices [3, 5]. Many researchers have reported the utilization of ferrites for water vapors detection as humidity sensitive active elements. Because the ferrites behave as a *n*-type semiconductor, conductivity will be increased in the presence of water vapor [4].

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Materials and Methods

Sample Preparation and Characteristic Measurements

Magnesium ferrite $MgFe_2O_4$ was prepared by solid state reaction method using Analar grade Magnesium Oxide, MgO and Ferric Oxide, Fe_2O_3 were weighed with stoichiometric composition. The mixture powder was ground by an agate motor for 3 h to be homogeneous and to obtain fine grain powders. The powder was then annealed at 1100°C for 22 h in the vacuum chamber using FOTEK MT-20 temperature controller. The K-type thermocouple was used as the temperature sensor. Photograph of experimental setup of sample preparation system is shown in Fig 1.

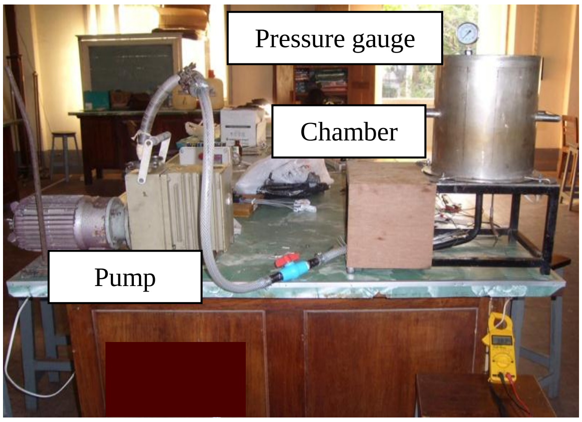

Fig 1 Photograph of the experimental setup of sample preparation system

Microstructural properties of the sample were investigated by using JEOL JSM-5610LV Scanning Electron Microscope SEM with the accelerating voltage of 15 kV, the beam current of 50 mA and 10000 times of photo magnification. Temperature dependent resistances of the $MgFe_2O_4$ pellet sample (1.20 cm in diameter and 0.26 cm in thickness) were observed in the temperature range 300 K – 973 K. Photograph of the experimental setup of temperature dependent electrical conductivity measurement is shown in Fig 2.

Fig 2 Experimental setup of temperature dependent electrical conductivity measurement

Results and Discussion

Microstructural Analysis: SEM micrograph of the $MgFe_2O_4$ sample as shown in Fig 3. The morphological features of the grain shape of the sample are circular shape and the grain sizes are 0.10 μm – 0.40 μm. Most of the samples are found to be homogeneous.

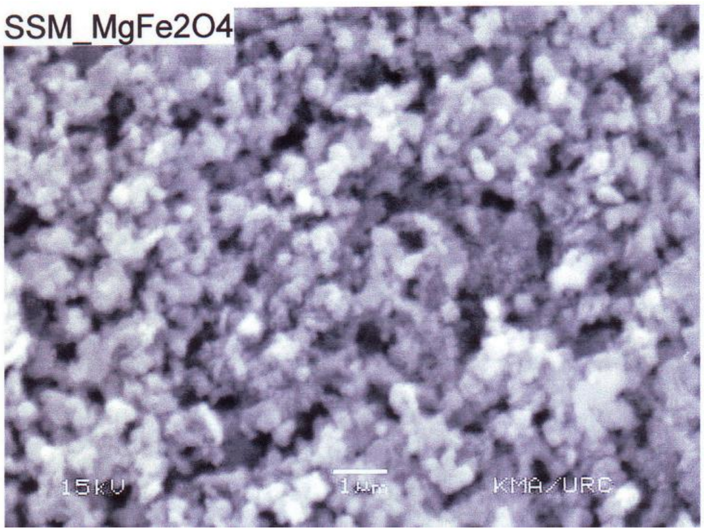

Fig 3 SEM micrograph of Magnesium Ferrite, $MgFe_2O_4$

Temperature Dependent Electrical Conductivity Study

Temperature dependent electrical conductivity of a ferrite obeys an Arrhenius expression $\sigma = \sigma_0 \exp(-E_i / kT)$, where σ is the conductivity, σ_0 is the pre-exponential factor, E_i is the activation energy for ionic conduction, *k* is the Boltzmann constant and *T* is the absolute temperature. Arrhenius plot of $MgFe_2O_4$ in the temperature range 300 K - 973 K is shown in Fig 4. Temperature dependent electrical conductivities of the sample are increased with increasing temperatures due to the interstitial diffusion of oxygen in the sample. Electrical conductivities of the sample are obtained as 6.31×10^{-9} S cm^{-1} (at 300 K) and 5.17×10^{-5} S cm^{-1} (at 973 K) respectively. The activation energy is obtained as 0.34 eV and the sample is a superionic conductor or fast ion conductor at ($T \geq 823$ K) because the electrical conductivity is ~ 10^{-5} S cm^{-1} at $T \geq 823$ K. The experimental data are tabulated in Table 1.

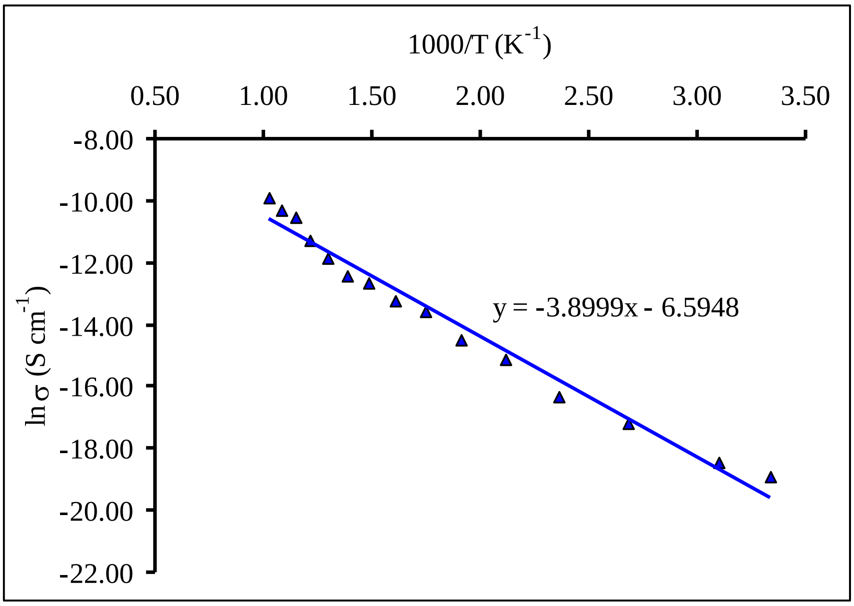

Fig 4 Arrhenius plot of the ln σ versus reciprocal temperature of $MgFe_2O_4$

Table 1 Experimental data of temperature dependent electrical conductivity measurement

T(K)	1000/T (K^{-1})	R (Ω)	σ (S cm^{-1})
300	3.33	36700000	6.31E-09
323	3.10	24000000	9.65E-09
373	2.68	6650000	34.80E-09
423	2.36	2780000	83.30E-09
473	2.11	830000	279.00E-09
523	1.91	453000	511.00E-09
573	1.75	180000	1290.00E-09
623	1.61	130000	1780.00E-09
673	1.49	73800	3140.00E-09
723	1.38	56900	4070.00E-09
773	1.29	32500	7130.00E-09
823	1.22	18700	12400.00E-09
873	1.15	8850	26200.00E-09
923	1.08	6680	34700.00E-09
973	1.03	4480	51700.00E-09

Conclusion

Magnesium ferrite, $MgFe_2O_4$ was prepared by solid state reaction method. Microstructural and temperature dependent electrical conductivity were reported by SEM and temperature dependent electrical conductivity measurements. SEM micrograph shows the grain shape is the circular shape and the sizes are 0.10 μm – 0.40 μm. The electrical conductivities are obtained as 6.31×10^{-9} S cm^{-1} (at 300 K) and 5.17×10^{-5} S cm^{-1} (at 973 K) respectively. The activation energy is obtained as 0.34 eV. The sample is a superionic conductor or fast ion conductor at high temperatures ($T \geq 823$ K). The sample can be considered as the solid electrolyte materials or fast ion conductors at high temperatures.

Acknowledgement

The authors would like to acknowledge Professor Dr Pho Kaung, Pro-Rector, University of Yangon for his permissible to use the Universities' Research Centre (URC) facilities.

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