Synthesis, Characterization and Investigation Magnetic and Photovoltaic Properties of FeVO₄ Nanoparticles

S. M. Hosseinpour-Mashkani, A. Sobhani-Nasab*, M. Maddahfar

Young Researchers and Elites Club, Arak Branch, Islamic Azad University, Arak, Iran

INTRODUCTION

In the past few decades, the studies of nanoparticles system have been extensively a subject of continue interest in chemistry, physic, and other fields [1-5]. Multiferroics are new class of materials, attracting attention because of simultaneous presence of more than one ferroic orders, especially magnetic and ferroelectric ordering [6-7]. Transition metal based orthovanadates (AVO₄) are the cohesive class of materials which have potential applications in various fields. So far, different vanadates such as BiVO₄, CeVO₄, LaVO₄, PrVO₄, GdVO₄, and NdVO₄ [8-13], have been synthesized and characterized. They have been used as catalysts, cathode materials in lithium ion batteries, gas sensors, solar cells, photoluminescence, microwave applications, optical fibres, scintillator materials, and humidity sensors. Among the metal vanadates, FeVO₄ is a highly stable and highly selective catalyst that finds many applications including photo catalytic degradation of the organic pollutants [14], gas sensor materials in detecting H₂S trace in air environment [15], electro chromic electrodes [16] and various other applications. FeVO₄ has four different polymorphs named as FeVO₄-I, FeVO₄-II, FeVO₄-III, and FeVO₄-IV, of which FeVO₄-I is a stable phase formed at room temperature while others are metastable phase that are usually formed at high pressure and high temperature [17]. In FeVO₄-I, Fe³⁺ ions have three crystallographic sites of which two sites are distorted octahedral FeO₆ and one site is in distorted trigonalbipyramidal FeO₆ environment. Fe-O polyhedra forms 6 columns doubly bent chain and the chains are joined together by VO₄ tetrahedra to form three dimensional frame works [18]. Among various
methods for the preparation of nanostructures, ultrasonic method is more promising in terms of low cost, simply control the shape, and particle size, low processing temperature, simplicity and potential for large-scale production. Recently, the ultrasonic process as a fast, convenient, and economical method has been widely used to generate novel nanostructure materials under ambient conditions [19-22]. Therefore, in this study in order to extend the ultrasonic method for preparation of inorganic vanadate nanoparticles, we report the preparation of FeVO$_4$ nanoparticles by ultrasonic method in an aqueous solution. The as-synthesized FeVO$_4$ nanoparticle was utilized as the photo-anode material for fabrication of FTO/TiO$_2$/FeVO$_4$/Pt-FTO solar cell structure to examine its solar cell application. Furthermore, the nature of magnetization applied field (M–H) infers paramagnetic behaviour for FeVO$_4$ nanoparticles.

MATERIALS AND METHODS

Characterization

X-ray diffraction (XRD) pattern was recorded by a Philips-X'PertPro, X-ray diffractometer using Ni-filtered Cu Kα radiation at scan range of 10°-20°<80. Scanning electron microscopy (SEM) images were obtained on LEO-1455VP equipped with an energy dispersive X-ray spectroscopy. The energy dispersive spectrometry (EDS) analysis was studied by XL30, Philips microscope. Photocurrent density-voltage (J-V) curve was measured by using computerized digital multimeters (Ivium-n-Stat Multichannel potentiostat) and a variable load. A 300 W metal xenon lamp (Luzchem) served as assimilated sun light source, and its light intensity (or radiant power) was adjusted to simulated AM 1.5 radiation at 100 mW/cm$^2$ with a filter. The magnetic measurement of sample was carried out in a vibrating sample magnetometer (VSM) (Meghnatis Daghigh Kavir Co.; Kashan Kavir; Iran) at room temperature.

Fabrication of FTO/TiO$_2$/FeVO$_4$/Pt-FTO Cell

Electrophoresis deposition (EPD) was utilized to the prepare TiO$_2$ films. During EPD, the cleaned FTO glass remained at a positive potential (anode) while a pure steel mesh was used as the counter (cathode) electrode. The linear distance between the two electrodes was about 3 cm. Power was supplied by a Megatek Programmable DC Power Supply (MP-3005D). The applied voltage was 10 V. The deposition cycle was repeated 4 times, each time 5s, and the temperature of the electrolyte solution was kept constant at 25 °C. The coated substrates were air dried. The apparent area of the film was 1 x 1 cm$^2$. The resulted layer was annealed under an air flow at 500 °C for 30 min. Electrolyte solution consisted of 120 mg/l of I$_2$, 48 ml/l of acetone, and 20 ml/l of water. For deposition of FeVO$_4$ powder on the FTO glass substrate, a paste of FeVO$_4$ was initially prepared. The slurry was produced by mixing and grinding 1.0 g of the nanometer sized FeVO$_4$ with ethanol and water in several steps. Afterwards, the ground slurry was sonicated with ultra-sonic horn (Sonicator 3000; Bandeline, MS 72, Germany, Tihorn, 20 kHz, 60 W cm$^2$) immersed directly in the reaction beaker where the reaction was performed in an air flow at 450 °C for 30 min. Counter-electrode was made from deposition of a Pt solution on FTO glass. Afterwards, this electrode was placed over TiO$_2$/FeVO$_4$ electrode. Sealing was accomplished by pressing the two electrodes together on a double hot-plate at a temperature of about 110 °C. The redox electrolyte consisting of 0.05 M of LiI, 0.05 M of I$_2$, and 0.5 M of 4-tert-butylypyridine in acetonitrile as a solvent was introduced into the cell through one of the two small holes drilled in the counter electrode. Finally, these two holes were sealed by a small square of sealing sheet and characterized by I-V test.

Synthesis of FeVO$_4$ nanoparticles

All the chemicals used in this method were of analytical grade and used as-received without any further purification. Ultrasonic irradiation was accomplished using a high-intensity ultrasonic probe (Sonicator 3000; Bandeline, MS 72, Germany, Tihorn, 20 kHz, 60 W cm$^2$) immersed directly in the reaction solution. At first, 1 mmol of NH$_4$VO$_3$ was dissolved in 15 ml of distilled water under ultrasonic irradiation at room temperature. In the second step, 1 mmol of Fe(NO$_3$)$_3$·9H$_2$O was dissolved in 15 ml of distilled water and was added drop-wise to the above solution under stirring. Then, the final mixtures were loaded into a beaker where the reaction was performed in an ultrasonic digestion system at 75 w for 10 min. Afterwards, the product was dried in vacuum at 80 °C for 3 h. Finally, the as-prepared products by ultrasonic
method were calcined at 550 °C in air for 2.5 h.

RESULTS AND DISCUSSION

The XRD pattern of the as-synthesized FeVO₄ nanoparticles at 75 W for 10 min is shown in Fig. 1. Extremely broaden reflection peaks were observed in Fig. 1, which indicated fine particle nature of the obtained anorthic phase of FeVO₄ nanoparticles (space group P-1, JCPDS No. 71-1592) with the calculated cell parameter of a= 6.7190 Å, b= 8.0600 Å, and c= 9.2540 Å. No other crystalline phases were detected in the calcined product. From XRD data, the crystallite diameter (D_c) of FeVO₄ nanoparticles (75 W for 10 min) was calculated to be 25 nm using the Scherer equation [23]:

$$D_c = \frac{K\lambda}{\beta\cos\theta}$$

where β is the breadth of the observed diffraction line at its half intensity maximum, K is the so-called shape factor, which usually takes a value of about 0.9, and λ is the wavelength of X-ray source used in XRD.

EDS analysis was used to evaluate the chemical composition and purity of final products (Fig. 2). The EDS spectrum of FeVO₄ nanoparticles shows the presence of Fe, O, and V elements in these nanoparticles. Furthermore, neither N nor C signals are detected in the EDS spectrum, which means the product is pure and free of any surfactant or impurity.

The morphology of the FeVO₄ nanoparticles has been examined by SEM image (Fig. 3). According to the Fig. 3, it is seen that the products composed of small spherical shapes nanoparticles with average size of about 35 nm.

The magnetization (M) of the FeVO₄ nanoparticles as a function of external applied magnetic field (H) at room temperature was measured. Fig. 4 shows the hysteresis loop of FeVO₄ nanoparticles. M-H curve exhibit magnetization of 0.17 emu/g and is an indicative of paramagnetic behavior.
I-V characterization of a typical solar cell fabricated using in situ approach is shown in Fig. 5. The measurement of the current density voltage (I-V) curve for FeVO$_4$ nanoparticles was carried out under the illumination of AM1.5 (100 mW/cm$^2$). Device characteristics are as follows: $V_{oc} = 0.3$ V, $J_{sc} = 0.133$ mA/cm$^2$, $\eta = 0.13$, and FF = 3.33 for FTO/TiO$_2$/FeVO$_4$/Pt-FTO.

Fig. 5. I-V characterization of the FTO/TiO$_2$/FeVO$_4$/Pt-FTO.

CONCLUSIONS

In summary, we have demonstrated the synthesis of FeVO$_4$ nanoparticles from ammonium metavanadate powder by ultrasonic process. The nature of M-H curve represents paramagnetic behaviour in FeVO$_4$ nanoparticles. A preliminary study on the possibility of developing a solar cell having FTO/TiO$_2$/FeVO$_4$/Pt-FTO structure was also performed.

ACKNOWLEDGMENT

Authors are grateful to University of Arak and VSM institute, Meghnatis Daghigh Kavir Co.; Kashan Kavir; Iran, for providing financial support to undertake this work.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

AUTHOR(S) BIOSKETCHES

Sobhani-Nasab, A., Ph.D Candidate, Young Researchers and Elites Club, Arak Branch, Islamic Azad University, Arak, Iran. Email: ali.sobhaninasab@gmail.com

Hosseinpour-Mashkani, S.M., M.Sc., Young Researchers and Elites Club, Arak Branch, Islamic Azad University, Arak, Iran. Email: hosseinpourmw@gmail.com

Maddahfar, M., M.Sc., Young Researchers and Elites Club, Arak Branch, Islamic Azad University, Arak, Iran. E-mail: maddahfar2010@gmail.com

REFERENCES


How to cite this article:
DOI: 10.7508/jns.2016.01.011
URL: http://jns.kashanu.ac.ir/article_13647.html