Semiconductor Physics, Quantum Electronics & Optoelectronics, 2024. V. 27, No 3. P. 298-301.

Thermophysical properties of manganese ferrite nanoparticles and manganese ferrite samples irradiated with γ-rays

A.F. Gochuyeva

Azerbaijan State Oil and Industry University, 20 Azadlig Avenue,
Baku AZ1010, Azerbaijan
E-mail: aynuragochuyeva@gmail.com

Abstract. In this article, thermophysical properties of manganese ferrite nanoparticles and 4×15×5 mm manganese ferrite samples in the tablet form prepared of these nanoparticles were investigated. The tablet samples were irradiated with γ-rays for 1 and 5 hours. After irradiation, physical characteristics of the heat flux of these samples were measured using a differential scanning calorimeter. Differential scanning calorimeter spectrum of the manganese ferrite nanoparticles was measured at –100...550 °C. The measurements for the irradiated samples were carried out in the temperature range of 0...550 °C.

Keywords: manganese ferrite nanoparticles, thermophysical characteristics, differential scanning calorimetry.

https://doi.org/10.15407/spqeo27.03.298
PACS 07.20.Fw, 07.85.-m, 61.80.-x, 81.70. Pg

Manuscript received 10.11.23; revised version received 03.06.24; accepted for publication 11.09.24; published online 20.09.24.

1. Introduction

Manganese ferrite nanoparticles ($MnFe_2O_4$) are among the most studied materials nowadays due to their numerous specific properties such as magnetization, extreme paramagnetism, single domain effect and unique magnetic properties such as spin filtering. Moreover, manganese ferrite nanoparticles and thin films have high spin glass state, extreme magnetization depending on the nanoparticle size, extreme paramagnetism, high anisotropy constant and high Curie temperature. Manganese ferrite nanoparticles have better mechanical, luminescence and magnetic properties than other existing magnetic ferrite nanoparticles [1–7]. Many technologies such as co-precipitation, sol-gel, mechanical-chemical, hydrothermal, solvo-thermal and reverse micelle have been developed to obtain $MnFe_2O_4$ nanoparticles. The manufacturing technology of manganese ferrite nanoparticles has a direct effect on their physical properties. For example, the precipitation method is more convenient for obtaining nanoferrites due to increased homogeneity, high purity and reactivity. This method is based on a relatively simple mechanism and allows optimizing the dependence of the particle size on temperature, pH and uncomplexed (not compounded) salt used. Nanoparticles prepared by conventional methods exhibit low-saturation magnetization under the influence of the layer. Chemical methods were found to be more suitable to synthesize nanomagnetic particles. Among these methods, sol-gel self-combustion method has attracted great attention for synthesizing spinel $MnFe_2O_4$ nanoparticles [8, 9].

In this work, thermophysical properties of manganese ferrite nanoparticle compound in the form of tablets irradiated with γ-rays for 1 and 5 hours were studied by analytical methods.

2. Research objects and methods

A sample of $MnFe_2O_4$ (SkySpring Nanomaterials, USA) with a density of 4.96 g/cm^3, a nanoparticle size of 60 nm and a chemical purity of 98.5% was used. This sample was placed into a special mold with a width of 4 mm, a length of 15 mm, and a height of 5 mm and pressed into a tablet form at a pressure of 50 kg/cm^2. A pressing process Model no. Hydraulic Press FTIR with ATHP-15 was performed in a full laboratory hydraulic press. The samples in the form of tablets were irradiated with γ-rays for 1 and 5 hours. Then the thermophysical properties of these samples were studied by analytical methods. The physical characteristics of the heat flux were measured using a differential scanning calorimeter (DSC) DSC 204 F1 Phoenix, Germany. The DSC spectrum of the manganese ferrite sample was recorded in the temperature range of –100 °C to 550 °C.

3. Analysis and discussion of the experimental results

The physical characteristics of heat flux encompass degradation mechanisms, structural transformations in nanoparticles, chemical reactions, and oxidation processes. Moreover, it is possible to switch from the heat flux function to thermodiffusion, heat capacity, thermal conductivity, and other thermodynamic parameters. Understanding the transition from the heat flux function to the heat capacity as well as the temperature dependence of the heat capacity elucidates the mechanisms underlying the changes in the thermodynamic functions. Fig. 1 presents the DSC curves for a manganese ferrite nanoparticle composite over the temperature range of –100 °C to 550 °C. The heat flux value (heat flow rate) ΔΦ was analyzed at a constant rate of thermal processing of 10 K/min. As can be seen from Fig. 1, the heat flux function contains three main segments characterized by particular time, heat flux function and sensitivity values. The transformations resulting from the application of heat to the crystal structure were identified and analyzed based on the peaks at the temperatures T_1 = 7.9 °C, T_2 = 20.8 °C, and T_3 = 67.3 °C. Fig. 2 illustrates the energy kinetics of the areas corresponding to these peaks in the temperature range of –100 °C to 550 °C. In the DSC spectrum, the value of the heat flux function decreases to –0.6 mW/mg at certain points [10].

In the temperature range 5 °C ≤ T ≤ 14.2 °C, where a peak at 7.9 °C is observed, the energy of the field amounts to 47.23 mJ, the enthalpy is calculated to be 4.925 J/g, and the heat flux function remains constant. In the temperature range 15.2 °C ≤ T ≤ 31.3 °C, where a peak is present at 20.8 °C, the energy of the field is found to be 9.56 mJ, the enthalpy is 1.543 J/g, and the heat flux function decreases from –0.12 to –0.15 mW/mg. In the temperature range 54.7 °C ≤ T ≤ 82.3 °C, where a peak is at 67.3 °C, the energy of the field is equal to 408.14 mJ, the enthalpy is 51.09 J/g, and the heat flux function remains constant. In the indicated temperature range, the observed effects are characterized by a linear decrease in the heat flow parameters of the manganese ferrite nanoparticle composite and a slight change in the central peaks. These changes are due to the reaching the resonance limit by vibrating atoms in the crystal structure and breaking of relatively weak atom bonds [10].

After 1-hour γ-irradiation of the rectangular manganese ferrite sample, the values of the heat of possible thermal transformations were determined using the DSC as mentioned above. The central peaks corresponding to these effects were found at T_1 = 93.4 °C and T_2 = 308.8 °C. Fig. 3 shows the energy kinetics of the areas corresponding to the peaks formed in the temperature range 0 °C ≤ T ≤ 550 °C. Based on the analysis of the DSC spectrum, the decrease of the heat flux function value to 0.07 mW/mg was found [11, 12].

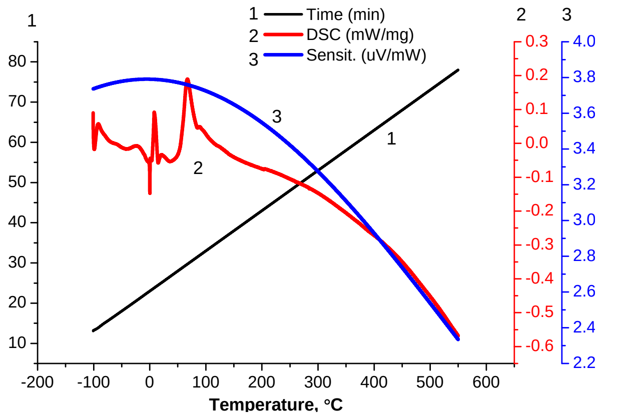

Fig. 1. DSC spectrum of a nanomanganese ferrite compound in the temperature range of –100 °C ≤ T ≤ 550 °C. (Color online)

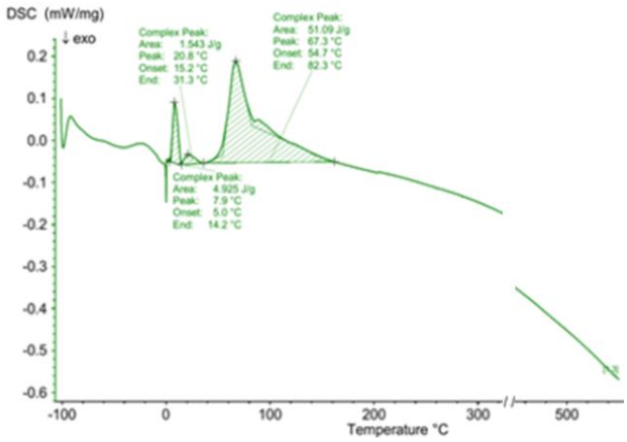

Fig. 2. Energy kinetics of the fields corresponding to the peaks formed in the temperature range –100 °C ≤ T ≤ 550 °C.

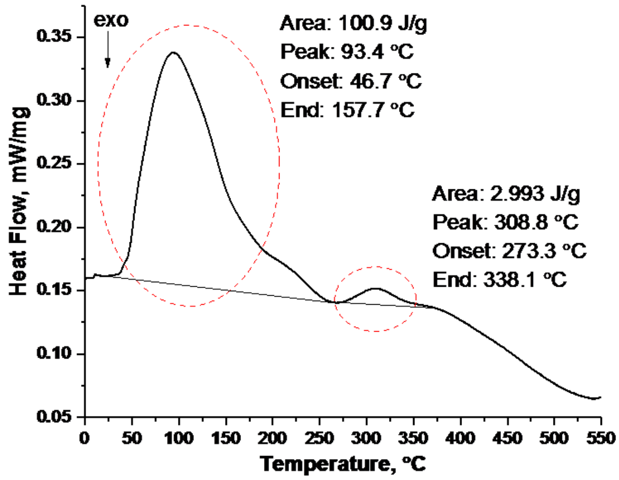

Fig. 3. Energy kinetics of the areas corresponding to the peaks formed in the temperature range –100 °C ≤ T ≤ 550 °C of the manganese ferrite sample irradiated by γ-rays for 1 hour.

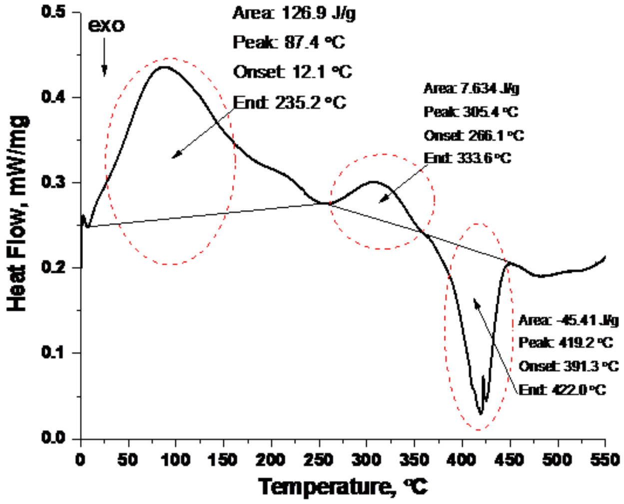

Fig. 4. Energy kinetics of the areas corresponding to the peaks formed in the temperature range 0 °C ≤ T ≤ 550 °C of the manganese ferrite sample irradiated by γ-rays for 5 hour.

The thermal transformation in the temperature range 46.7 °C ≤ T ≤ 157.7 °C corresponding to the peak at 93.4 °C is characterized by the energy of 2105 mJ, the enthalpy of 100.9 J/g, and the decrease in the thermal flux function from 0.16 to 0.15 mW/mg. The transformation corresponding to the peak at 308.8 °C, occurring in the temperature range 273.3 °C ≤ T ≤ 338.1 °C, is characterized by the energy of 48.6 mJ, the enthalpy of 2.993 J/g, and the increase in the thermal flux function from 0.14 to 0.15 mW/mg.

As mentioned above, the rectangular manganese ferrite tablets were irradiated with γ-rays for 5 hours. The physical characteristics of the heat flow of the sample were measured and analyzed using DSC. Thermal transformations due to the application of heat were detected. The corresponding peaks were observed at the temperatures T_1 = 87.4 °C, T_2 = 305.4 °C, and T_3 = 419.2 °C. Fig. 4 shows the energy kinetics of the areas corresponding to these peaks in the temperature range 0 °C ≤ T ≤ 550 °C. The value of the heat flux function in the DSC spectrum varies from 0.15 to 0.5 mW/mg. For the transformation in the temperature range 12.1 °C ≤ T ≤ 235.2 °C corresponding to the peak at 87.4 °C, the energy is found to be 365 mJ, the enthalpy is calculated to be 126.9 J/g, and the thermal flux function increases from 0.25 to 0.27 mW/mg. For the transformation corresponding to the peak at 305.4 °C in the temperature range 266.1 °C ≤ T ≤ 333.6 °C, the energy is equal to 14.6 mJ, the enthalpy is 7.634 J/g, and the thermal flux function decreases from 0.27 to 0.24 mW/mg. For the transformation corresponding to the peak at 419.2 °C in the temperature range 391.3 °C ≤ T ≤ 422.0 °C, the energy amounts to 847 mJ, the enthalpy is 45.41 J/g, and the thermal flux function remains constant.

4. Conclusions

It was determined by thermal analysis that the studied ferrite nanoparticles samples undergoes phase transition in the temperature range –100 °C ≤ T ≤ 550 °C. It was determined from the DSC spectrum that the field energies characterizing the effects corresponding to the peaks formed in the sample in the temperature range –100 °C ≤ T ≤ 550 °C were in the range of 47.23 to 408.14 mJ and the enthalpy ranged from 4.925 to 51.09 J/g. It was also shown experimentally that the value of the thermal flux function decreased to 0.1...0.6 mW/mg. DSC analyzes of the sample γ-irradiated for 1 and 5 hours in the temperature range 0 °C ≤ T ≤ 550 °C showed that the field energies characterizing the effects corresponding to the peaks formed in the samples were in the range of 2105 to 48.6 mJ and 365 to 847 mJ, while the enthalpy ranged from 100.9 to 2.993 J/g. At this, the value of the thermal flux function varied between 0.07 and 0.15...0.5 mW/mg.

Acknowledgements

I express my deep gratitude to Fuad F. Yachyaev, an engineer at the İnstitute of Physics, Ministry of Science and Education, who helped me in carrying out the DSC analyses.

References

1. Kurbanov M.A., Suleymanov G.Z., Gochuyeva A.F. *et al*. Conductivity photoquenching effect in polymer–ferrocene composites. *Semiconductors*. 2011. **45**. P. 503–509. https://doi.org/10.1134/S1063782611040130.
2. Gochuyeva A.F., Kurbanov M.A., Khudayarov B.H., Aliyeva A.M. Photoresistive effect in the composites consisting of organic and inorganic photosensitive semiconductors. *Dig. J. Nanomater. Biostruct.* 2018. **13**, No 1. P. 185–191.
3. Gochuyeva A.F., Hashimov Kh.Kh., Bayramov I.Y. Photoelectret effect in polymer-$A^{II}B^{VI}$ (CdS, ZnS) composites of photosensitive semiconductors. *Chalcogenide Lett.* 2023. **20**, No 4. P. 285–291. https://doi.org/10.15251/CL.2023.204.285.
4. Mammadova Z.M., Gurbanov M.A., Gochuyeva A.F. *et al*. Synthesis of mono and homobinuclear ferrocenylcarbinol derivatives and photoquenching effect of electroconductivity in their polyethylene composites. *European University of Applied Sciences, Chemistry*. 2014. No 11, Section 13. P. 108–109.
5. Suleymanov G.Z., Gurbanov M.A., Akbarov A.Kh. *et al*. Synthesis of mono-, bi- and trinuclear carbinol derivatives of ferrocene, development of technologies obtaining of thin coverings of photocomposites with polymer matrixes and study of some electrophysical properties. *Azerbaijan Chem. J.* 2017. No 4. P. 50–56.
6. Gochuyeva A.F., Hashimov Kh.Kh. New technologies of matrix composite polymer photovoltaic and photoelectret materials. *New Materials, Compounds and Applications*. 2023. **7**, No 3. P. 194–201.

7. Kerimov M.K., Kurbanov M.A., Bayramov A.A. *et al*. New technologies of matrix composite polymer photovoltaic and photoresistive materials. *J. Scientific Israel – Technological Advantages*. 2012. **14**, No 4. P. 9–15.
8. Gochuyeva A.F. Structural and magnetic properties of manganese ferrite nanoparticles. *Mod. Phys. Lett. B*. 2023. **37**, No 10. P. 2350005. https://doi.org/10.1142/S0217984923500057.
9. Rajpoot M., Mumtaz M., Ali H. *et al*. Effect of lithium doping on frequency-dependent dielectric properties of manganese ferrite nanoparticles. *Appl. Phys. A*. 2024. **130**, No 2. P. 99. https://doi.org/10.1007/s00339-023-07251-3.
10. Gochuyeva A.F. Thermophysical and structural properties of manganese ferrite nanoparticles. *Mod. Phys. Lett. B*. 2022. **36**, No 2. P. 2150542. https://doi.org/10.1142/S021798492150542.
11. Mirzayev M.N. Oxidation kinetics of boron carbide ceramic under high gamma irradiation dose in the high temperature. *Ceram. Int.* 2020. **46**, No 3. P. 2816–2822. https://doi.org/10.1016/j.ceramint.2019.09.273.
12. Mirzayev M.N. Simultaneous measurements of heat flow rate and thermal properties of nano boron trioxide under neutron irradiation at the low and high temperature. *Vacuum*. 2020. **173**. P. 109162. https://doi.org/10.1016/j.vacuum.2019.109162.

Authors and CV

Aynura F. Gochuyeva, born in 1980, defended her Ph.D. thesis in Physics (Electronics) in 2014 at the Institute of Physics, Azerbaijan National Academy of Sciences. Associate Professor at the Azerbaijan State Oil and Industry University. Authored over 44 publications and 1 patent. The area of her scientific interests includes physics and technology of semiconductor materials, photoelectret, photovoltaic, anti-ferromagnetic materials, photoresistive effects in composite materials.
https://orcid.org/0000-0003-0445-6120

Теплофізичні властивості наночастинок фериту марганцю та зразків фериту марганцю, опромінених γ-променями

A.F. Gochuyeva

Анотація. У цій статті досліджено теплофізичні властивості наночастинок фериту марганцю та зразків фериту марганцю з розмірами 4×15×5 мм. Зразки фериту марганцю у вигляді таблеток опромінювали γ-променями протягом 1 та 5 годин. Після опромінення вимірювали характеристики теплового потоку для цих зразків за допомогою диференціального скануючого калориметра. Спектр диференціальної скануючої калориметрії наночастинок фериту марганцю вимірювали при –100 °C...550 °C. Вимірювання для опромінених зразкків проводили в діапазоні температур 0 °C...550 °C.

Ключові слова: наночастинки фериту марганцю, теплофізичні характеристики, диференціальна скануюча калориметрія.