Results in Physics 6 (2016) 824–825

Contents lists available at ScienceDirect

Results in Physics

journal homepage: www.journals.elsevier.com/results-in-physics

Microarticle

# Investigation on conductivity anomalies in ferrites using impedance spectroscopy

N.S.K. Kumar, T.S. Shahid, G. Govindaraj *

*Department of Physics, School of Physical, Chemical and Applied Sciences, Pondicherry University, Puducherry 605014, India*

ARTICLE INFO

*Article history:*
Received 13 October 2015
Accepted 2 December 2015
Available online 19 December 2015

*Keywords:*
Impedance/dielectric spectroscopy
Ac conductivity
Ferrites

ABSTRACT

Temperature dependent conductivity of materials is one prime interest of materials science. Many ferrite materials are reported showing conductivity anomalies with temperature. $CoFe_2O_4$, $Mn_{0.5}Zn_{0.5}Fe_2O_4$ and $SrFe_{12}O_{19}$ are studied for the conductivity anomalies with impedance spectroscopy. Conductivity data of the samples obtained during heating show anomalies with temperature, while during cooling do not show any anomalies and follow Arrhenius behaviour. The anomalies in ac conductivity $\sigma'(\omega)$ and dielectric constant $\varepsilon'(\omega)$ corroborated with the TGA and it is attributed to the absorption of water by the material before performing the experiment. Hence it is recommended to perform the electrical measurements during cooling of the sample from high temperature.



## 1. Introduction

Impedance spectroscopy is a suitable tool to study the electric and dielectric properties of materials of various kinds [1–3]. Several anomalies have been reported on the conductivity of ferrites with temperature. Metal to semiconductor transition is reported as conductivity decreases with increase of temperature (metallic behaviour) in the low temperature region. At high temperature range conductivity increases with an increase in temperature (semiconducting behaviour) [4–6]. In the present work, we investigate electrical behaviour of different ferrites using ac impedance spectroscopy by carrying out measurements for various temperatures by heating and cooling the sample.

## 2. Experiment

$CoFe_2O_4$ (CFO), $Mn_{0.5}Zn_{0.5}Fe_2O_4$ (MZFO) and $SrFe_{12}O_{19}$ (SFO) samples are synthesised by chemical co-precipitation method. CFO is synthesised with $Co(NO_3)_2 6H_2O$ and $Fe(NO_3)_3 9H_2O$. MZFO is synthesised with $MnCl_2.4H_2O$, $ZnCl_2$ and $FeCl_3$. SFO is synthesised with $Sr(NO_3)_2$ and $Fe(NO_3)_3.9H_2O$. NaOH is used as the precipitation agent for all the samples. CFO is made into pellet and sintered at 1073 K. MZFO is dried overnight and made into a pellet. SFO is calcinated at 1173 K and made into a pellet. The formation of samples is confirmed with powder X-ray diffraction and it is shown in Fig. 1. Complex impedance data of all the samples are taken for the frequency range of 0.1 Hz to 1 MHz in nitrogen ambience for various temperatures using Alpha-A analyser of Novocontrol instrument with quatro cryosystem of temperature accuracy 0.5 K. Electrical measurements have been carried out during heating of the sample from room temperature to higher temperature and then cooled to room temperature. Thermogravimetric analysis (TGA) of the sample is obtained with TA instruments Q600.

## 3. Results and discussion

Samples show conductivity anomaly on the measurement taken during heating from room temperature to higher temperature. MZFO and SFO show a decrease in conductivity with an increase in temperature near 373 K. The ac conductivity measurements during cooling do not show any conductivity anomaly and follows expected Arrhenius behaviour. The ac conductivity of all the samples at 10 Hz for various temperatures is shown in Fig. 2. TGA of all the samples shows loss of weight during heating of the sample and it is shown in Fig. 3. It indicates evaporation of absorbed water. The conductivity anomalies of the samples observed during heating of the sample are related to their corresponding TGA data. CFO shows less variation of weight loss (3%) in TGA and least conductivity anomaly during heating. SFO shows moderate weight loss (5%) and shows conductivity anomaly near temperature 373 K. The conductivity data during cooling of CFO and SFO do not follow

* Corresponding author.
*E-mail address:* ggraj_7@yahoo.com (G. Govindaraj).

http://dx.doi.org/10.1016/j.rinp.2015.12.005
2211-3797/© 2016 Published by Elsevier B.V.

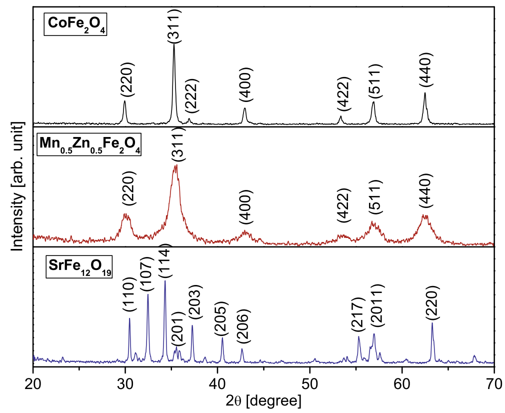


**Fig. 1.** X-ray diffraction pattern of samples.

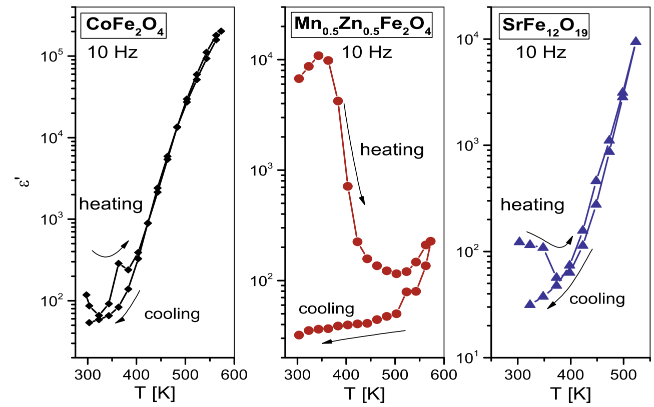


**Fig. 4.** Permittivity of samples at frequency 10 Hz for various temperatures.

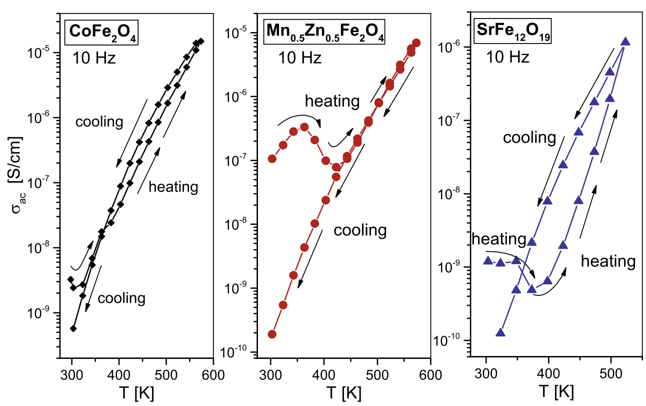


**Fig. 2.** Ac conductivity of the samples at frequency 10 Hz for various temperatures.

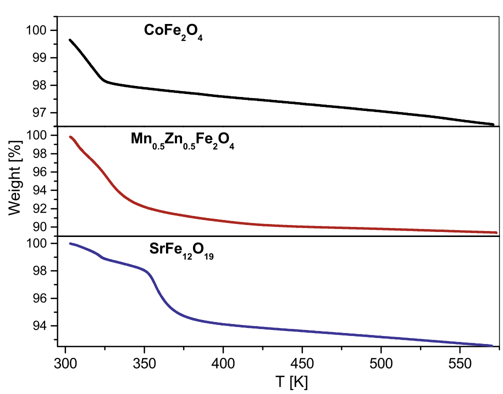


**Fig. 3.** Weight loss of samples with temperature.

the heating path. Weight loss of CFO and SFO continues up to 523 K. MZFO shows large weight loss of 10% and very large conductivity anomaly during heating. The conductivity data during cooling follow the heating path till 433 K. TGA data of MZFO also show no weight loss from 433 K to 560 K. From the above observations it is clear that absorbed water in the sample may leads to conductivity anomaly. Iqbal et al. observed similar conductivity anomaly in $Mg_{(1-x)}Co_xCr_xFe_{2-x}O_4$ during heating the sample and it is attributed to moisture deep within the pores of the sample pellet [7]. The dielectric constant $\varepsilon'$ also shows similar anomaly and it is shown in Fig. 4. As the temperature increases, the value of $\varepsilon'$ increases due to Maxwell–Wagner polarisation at low frequencies and high temperatures [8]. Heating the sample causes the reduction in the value of $\varepsilon'$ at room temperature since the absorbed water evaporates as observed by Iwauchi [9]. The absorbed water in the samples may increase or decrease the total conductivity [10].

## 4. Conclusion

Even after sintering the sample may absorb water from the atmosphere before performing the electrical measurements. This absorbed water in the sample leads to conductivity anomalies with temperature. This may cause the very large Maxwell–Wagner polarisation for low frequencies at low temperatures. The measurements taken during cooling do not show any conductivity anomaly with temperature and follows Arrhenius behaviour. Hence, it is recommended to perform electrical measurements during cooling the sample from higher temperature to avoid the free charge carriers created by absorbed water, even for the sintered sample.

## Acknowledgments

Authors thank Central Instrumentation Facility, Pondicherry University for the TGA and dielectric spectroscopy measurements. We acknowledge CSIR project 03(1279)/13/EMR-II for financial support. One of the authors (NSKK) acknowledges DST-PURSE for the financial support as project assistant.

## References


[1] Dyre JC, Schroder TB. Rev. Mod. Phys. 2000;72:873.
[2] Sailaja U, Thayyil MS, Kumar NSK, Govindaraj G. Eur. J. Pharm. Sci. 2012;49:333.
[3] Cheruku R, Govindaraj G, Vijayan L. Mater. Chem. Phys. 2013;141:620.
[4] Arunkumar A, vanitha D, Oudayakumar K, Rajagoapan S, Kannan R. J. Appl. Phys. 2013;114:183905.
[5] Younas M, Nadeem M, Atif M, Grossinger R. J. Appl. Phys. 2011;109:093704.
[6] ur Rahman A, Rafiq MA, Karim S, Maaz K, Siddique M, Hasan MM. J. Phys. D Appl. Phys 2011;44:165404.
[7] Iqbal MJ, Ahmad Z, Meydan T, Melikhov Y. J. Appl. Phys. 2012;111:033906.
[8] Koops CG. Phys. Rev. 1951;83:111.
[9] Iwauchi K. Japan J. Appl. Phys. 1971;10:1520.
[10] Truong L, Howard M, Clemens O, Knight KS, Slaterb PR, Thangadurai V. J. Mater. Chem. A 2013;1:13469.