Study of Dielectric and Magnetodielectric Properties of Y-Type $Ba_2Mg_{1.5}Ni_{0.5}Fe_{12}O_{22}$ Hexaferrite

Md. F. Abdullah[1*], P. Pal[1], S. Patel[1], K. Chandrakanta[1], R. Jena[1] and, A. K. Singh[1]*

[1]Department of Physics and Astronomy, National Institute of Technology Rourkela-769008, Odisha, India.

*Email: (faruck.ggv@gmail.com, singhanil@nitrkl.ac.in)

Abstract

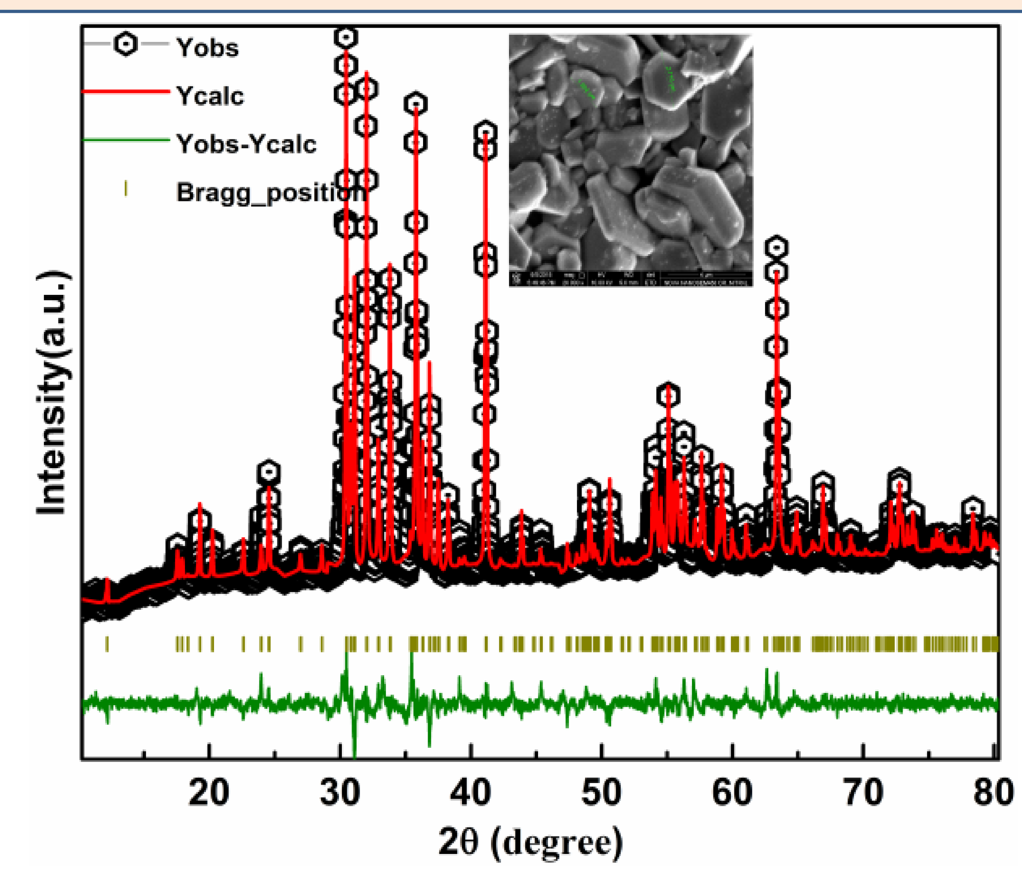
We have investigated dielectric, impedance and magnetodielectric (MD) properties of polycrystalline Y-type hexaferrite $Ba_2Mg_{1.5}Ni_{0.5}Fe_{12}O_{22}$ (BMNF). Rietveld refinement of the X-ray diffraction pattern and hexagonal plate-like Field Emission Scanning Electron Microscope (FESEM) micrograph confirms the phase purity with rhombohedral crystal structure (*R-3m* space group). Both temperatures dependent dielectric permittivity (ε′) and dielectric loss (tan δ) show an anomaly around 150°C and 290°C. The comparable value of activation energy extracted from impedance spectroscopy above 290°C between σ_g and σ_{gb} indicates that relaxation and conduction mechanism may be attributing to the same entities. Room temperature magnetodielectric (MD) measurement at 1MHz indicates the step like increase at ~8 kOe in dielectric constant (ε) with applied field but a reverse trend is observed for magneto-loss (ML) with step like feature preserving it nature.

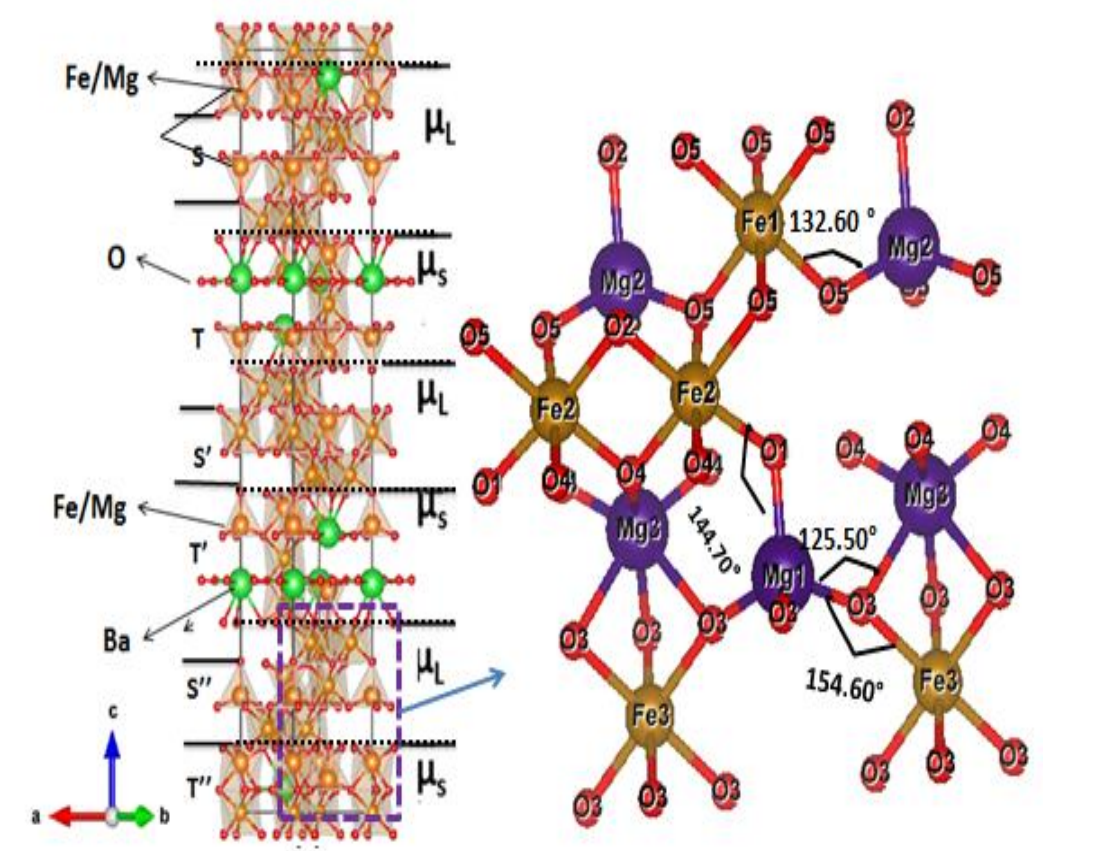
Introduction

- Hexaferrite materials continue to be interesting due to its potential electrical, dielectric and Magneto-electric coupling (MEC) properties at room temperature. [1]
- Recently, Y-type hexaferrite has attracted attention for their possibility of tailoring electrical, magnetic and ME properties by varying doping and sintering condition. [2]
- It is reported that, the magnetic ordering in Y-type $BaSrCoZnFe_{12}O_{22}$ can be modulated by Al doping at Fe site, which tunes magnetic anisotropy by decreasing polyhedral distortion. [3]
- Several reports on hexaferrite mainly focused on magnetic properties but very few materials have both high resistivity and ME properties.
- Controlled synthesis or suitable doping are one of the prominent process of getting enhanced properties in hexaferrite sample.

Experimental Results

Structural Characterization





- XRD refinement confirms that all the sample are properly crystallize with space group R-3m.

Table 1. The Superexchange Bond Angle and Bond Length of BMNF

Bond Angle	Bond Angle (degree)	Atoms	Bond length (Å)
Mg2-O5-Fe1	132.60° (14)	Fe1-O1	2.13066 (2)
Mg3-O3-Mg1	125.50° (10)	Fe2-O4	3.16472 (3)
Mg1-O3-Fe3	154.60° (18)	Fe2-O5	2.02691 (2)
Fe2-O1-Mg1	144.70° (10)	Fe3-O4	2.73398 (8)

Magnetodielectric Characterization

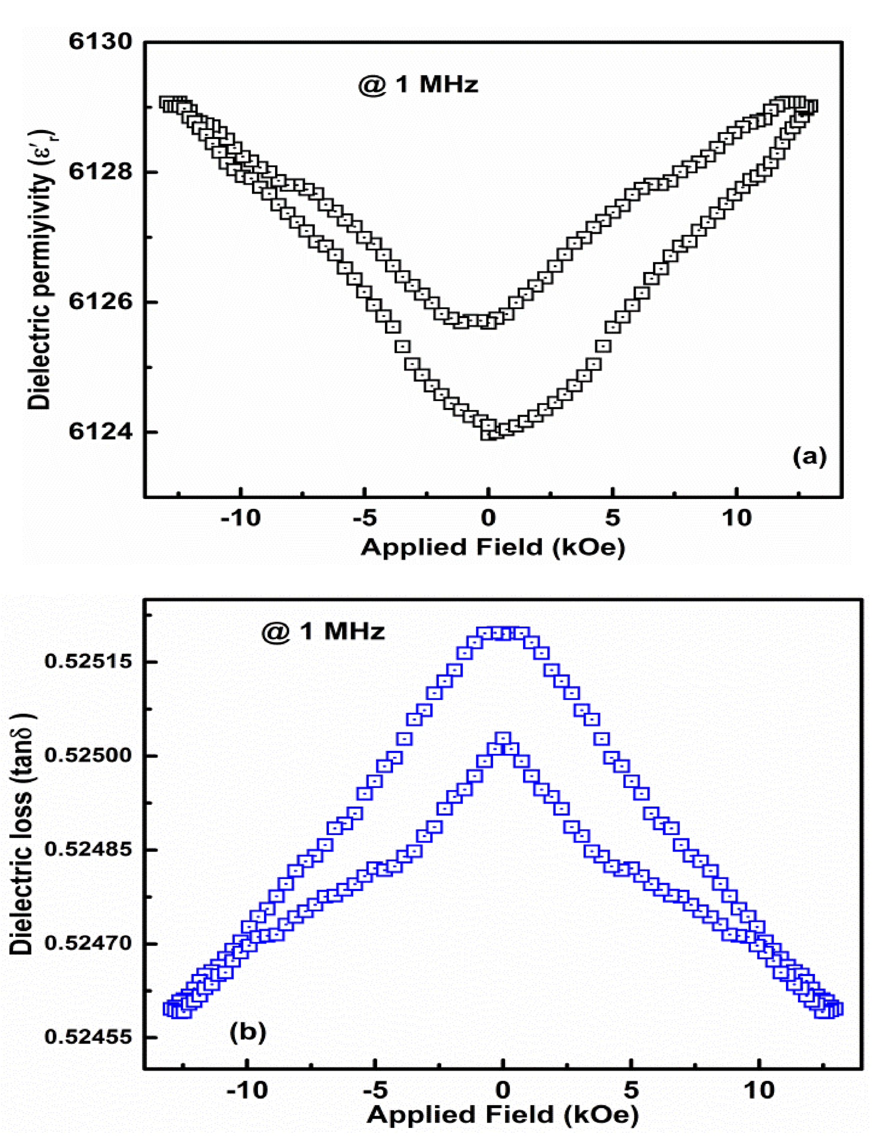
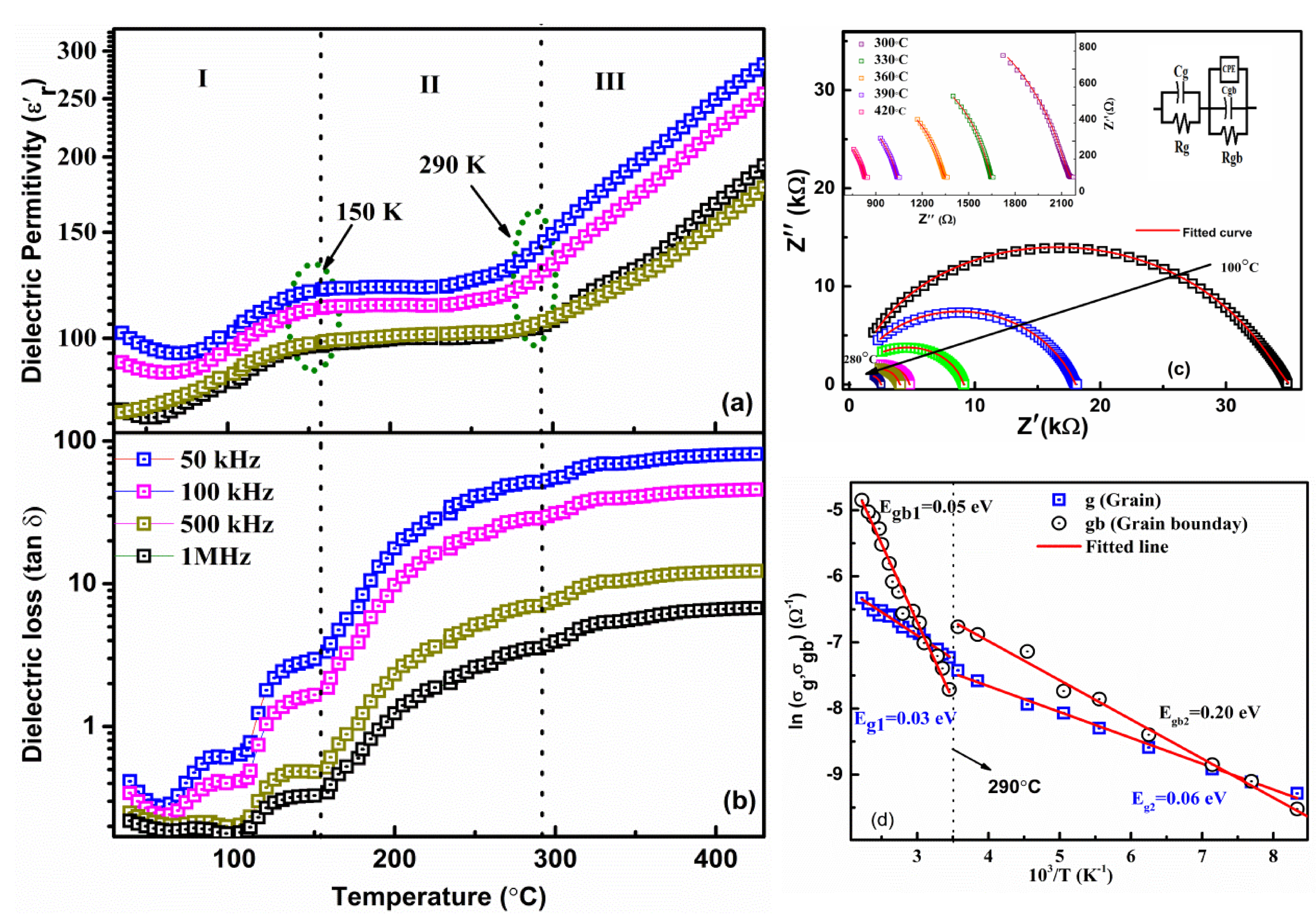


Figure show the variation of dielectric permittivity and dielectric loss at room temperature with an applied field of ±13 kOe.

$$MD\% = \frac{\varepsilon(H) - \varepsilon(0)}{\varepsilon(0)} \times 100$$

- Linear step like increase in MD% with H in BMNF sample.
- Distorted butterfly loop like MD effect with applied field
- The step at ~8 kOe may be due to evolution of different spin ordering in the sample with applied field.
- Interestingly, it is also noticed that dielectric loss decrease with applied field followed by step at ~8kOe.
- A detailed investigation needs to be done to understand the microscopic origin of MD effect at room temperature in the studied compound.

Dielectric and Impedance Characterization



- **Nyquist plots can be best fitted with the equivalent circuit by considering bricks-layer model. The equation of this equivalent circuit can be represented by:**

$$Z^* = Z' - jZ'' = \frac{1`}{R_g^{-1} + j\omega C_g} + \frac{1}{R_{gb}^{-1} + j\omega C_{gb} + A_0 (j\omega)^n}$$

Where, $$Z' = \frac{R_g}{1+(\omega R_g C_g)^2} + \frac{(1+A\omega^n)^2}{(1+A\omega^n)^2 + (B\omega^n + \omega R_{gb} C_{gb})^2}$$

$$Z'' = R_g\left[\frac{\omega R_g C_g}{1+(\omega R_g C_g)^2}\right] + R_{gb}\left[\frac{B\omega^n + \omega R_{gb} C_{gb}}{(1+A\omega^n)^2 + (B\omega^n + \omega R_{gb} C_{gb})^2}\right]$$

In which $A = A_0 R_{gb} \cos\left(\frac{n\pi}{2}\right)$, $B = A_0 R_{gb} \sin\left(\frac{n\pi}{2}\right)$

(R_g, C_g) and (R_{gb}, C_{gb}) are the resistance and capacitance of grain and grain boundary respectively

- **Arrhenius law,**

$\sigma = \sigma_0 \exp(E_g/k_B T)$

Where, σ_0 is prefactor, E is activation energy for response, k_B is Boltzmann constant, and T is absolute temperature.

- **The fitted value of n of constant phase element (CPE) is in range 0.65-0.31 and the value decrease with increase in temperature**

Conclusions

- The Reitveld refinement data of prepared sample are single phase rhombohedral with space group R-3 m.
- The temperature dependent dielectric permittivity and dielectric loss reveals anomalies around 150°C and 290°C.
- The dielectric impedance analysis shows that non-Debye-type relaxation present in the sample and above 290 °C, the relaxation and conduction mechanism may be attributed to the same entities.
- The room temperature magnetodielectric and magneto loss measurement shows distorted butterfly loop like hysteresis behavior with the applied field.

Acknowledgment

We acknowledge Board of research in Nuclear Science (BRNS), Mumbai (Sanction: 2012/37P/40/BRNS/2145) and Department of Science and Technology (DST), New Delhi (Sanction No: SR/FTP/PS-187/2011) for funding.

References

[1]Y. Iguchi, Y. Nii & Y. Onose,Nat. Commn **8**,(2017) 15252
[2]. Md F. Abdullah *et al.*, Physica B: Condensed Matter **70–75**(2019) 568.
[3]. F. Wang *et al.* Appl. Phys. Lett. **100** (2012) 122901.
[4]. G. W. Rathenau, Rev. Mod. Phys. **25** (1953) 297.
[5] K. Tanwar *et al.*, RSC Adv., 8(2018), 19600.
[6] G .Catalan , *Appl. Phys. Lett.* **88** (2006)102902.
[7] B. Ramachandran *et al., Appl. Phys. Lett.* **100** (2012)252902.