Physical Sciences

$Bi_2Fe_4O_9$ as a potential candidate for multiple state memory and magnetic field sensor application

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Keywords: Magneoelectric coupling, magnetic field sensors, magnetization, dielectric constant

Abstract

Phase pure polycrystalline $Bi_2Fe_4O_9$ is prepared using the conventional solid state reaction route. X-ray diffraction (XRD) reveals $Bi_2Fe_4O_9$ to possess an orthorhombic crystal structure with space group '*Pbam*'. Optical characterization confirms $Bi_2Fe_4O_9$ to be a direct band gap material with E_g ~ 1.5 eV. Magnetization measurement shows compound to be antiferromagnetic (AFM) with AFM transition temperature ~150 K. The dielectric response of the compound was recorded in the temperature range 10-300 K with the probing frequency from 500 Hz-5 MHz. Here, we report remarkable magnetic field tunable dielectric properties of polycrystalline $Bi_2Fe_4O_9$ near its AFM transition temperature. Thus, $Bi_2Fe_4O_9$ can be further stimulated for various other magnetic field sensors, multiple state memory and other ferroelectric applications.

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Phase pure polycrystalline $Bi_2Fe_4O_9$ is prepared using the conventional solid state reaction route. X-ray diffraction (XRD) reveals $Bi_2Fe_4O_9$ to possess an orthorhombic crystal structure with space group 'Pbam'. Optical characterization confirms $Bi_2Fe_4O_9$ to be a direct band gap material with Eg ~ 1.5 eV. Magnetization measurement shows compound to be antiferromagnetic (AFM) with AFM transition temperature ~150 K. The dielectric response of the compound was recorded in the temperature range 10-300 K with the probing frequency from 500 Hz-5 MHz. Here, we report remarkable magnetic field tunable dielectric properties of polycrystalline $Bi_2Fe_4O_9$ near its AFM transition temperature. Thus, $Bi_2Fe_4O_9$ can be further stimulated for various other magnetic field sensors, multiple state memory and other ferroelectric applications.

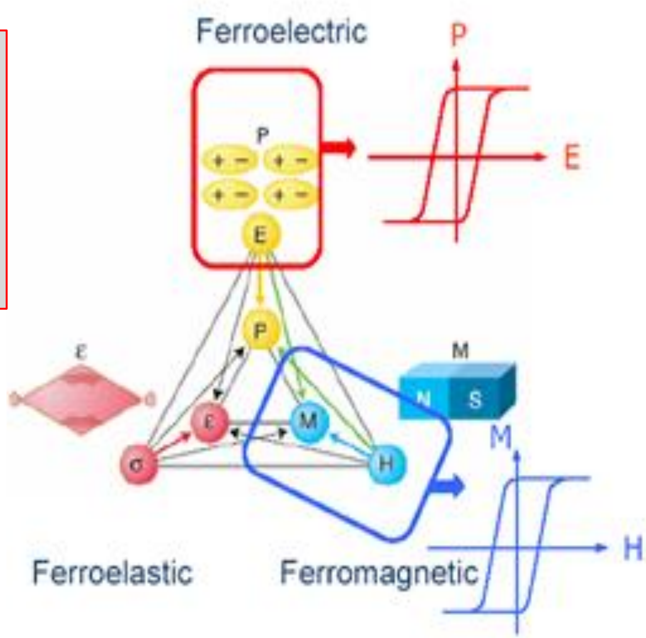
Plan of talk

- Introduction
- Motivation
- Experimental techniques used
- Results and discussion
- Conclusion

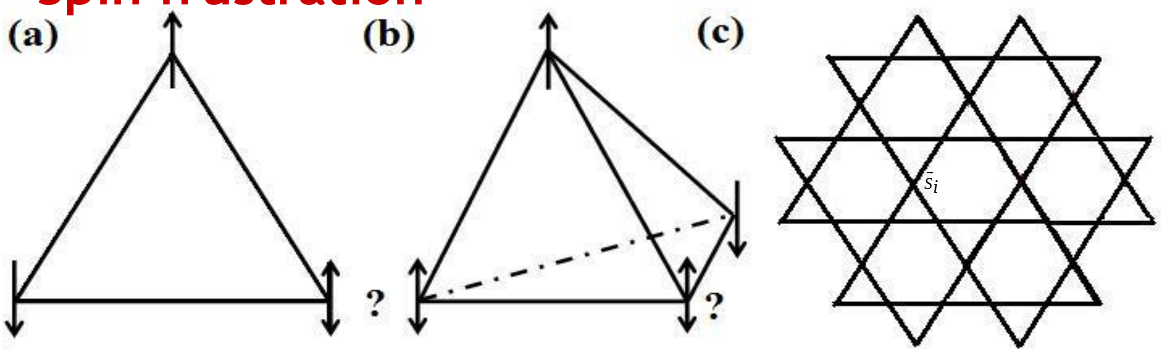
Introduction

Multiferroics

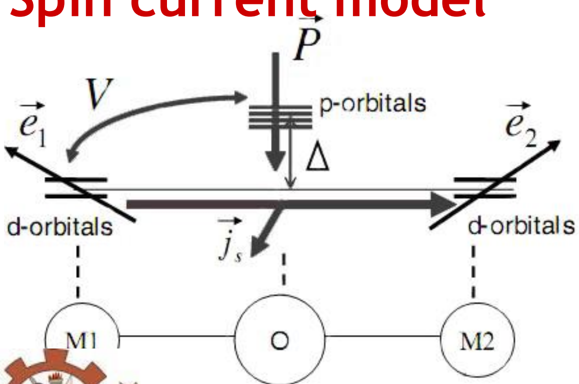
➢ Multiferroics are rare materials that exhibits two or more switchable states such as polarization, magnetization, or strain and possibly exhibiting coupling among them. *Spaldin, Science 309, 391 (2005)*



Spin frustration



Spin current model



$$\vec{P} = A\vec{e_{ij}} \times \left(\vec{S_i} \times \vec{S_j}\right)$$

S_i, S_j: magnetic moments
e_{ij}: unit vector connecting site I, j
P: polarization
J_s: spin current

Phys. Rev. Lett. **96**, 067601 (2006)

Examples of Multiferroics

- The most promising multiferroic materials are the Perovskites having structure like ABO_3. d-shell electrons plays the important role. e.g. $SrTiO_3$, $BaTiO_3$,$PbVO_3$ etc.
- Bi and Pb Perovskites : lone pair plays the role.
  e.g. $BiMnO_3$, $BiFeO_3$
- Hexagonal magnanites: Same formula as perovskite has .
  But different crystal and electronic structure e.g. $YMnO_3$.
- Ferroelectricity due to magnetic ordering e.g. $Ni_3V_2O_8$.
- Recently discovered RMn_2O_5 and $CdCr_2S_4$

Applications of Multiferroics

- ✓Magnetic field Sensors
[Appl. Phys. Lett. **88**, 62510 (2006), Nat. Mater. 7, 94 (2009)]
- ✓Data storage, and recording
[J. Appl. Phys. **103**, 07F506 (2008), J. Appl. Phys **102**, 44504 (2007)]
- ✓Quantum electromagnet [Science **312**, 1481(2006)]
- ✓Solar cells [Science 324, 64 (2009), Appl. Phys. Lett. 95, 62909 (2009)]
- ✓Microelectronics
[J. Phys.: Condens. Mater 17, L39 (2005)]
- ✓Transducers
- ✓Detectors (SONAR) :
- ✓Filter probes and filters
- ✓Spintronics applications

Scarcity of multiferroics: why?

There are some limiting factors that prevent a material to be simultaneously ferromagnetic and ferroelectric :---

✓**Symmetry:** There are 122 no. of Shubnikov point groups. Among these 31 are allowed for electric polarization **P,** and 31 are allowed for magnetic polarization **M** & 13 point groups are common to both.

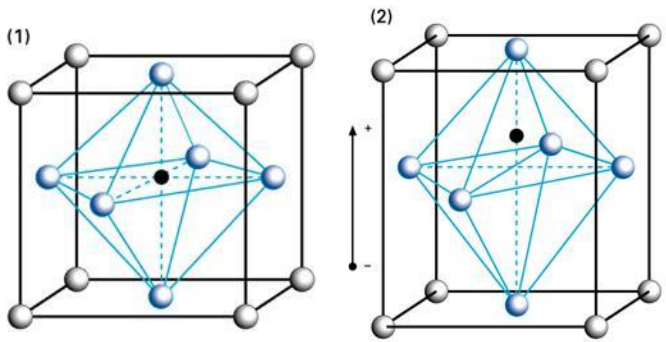
✓**Electric property:** Ferroelectric materials must be an insulator and Ferro magnets are often metal. So it is difficult to exist both these ferroic properties in a same material.

✓**d^0-ness:** Ferroelectric material have d^0 configuration but ferromagnetism needs partially d-filled orbital. Again contradiction.

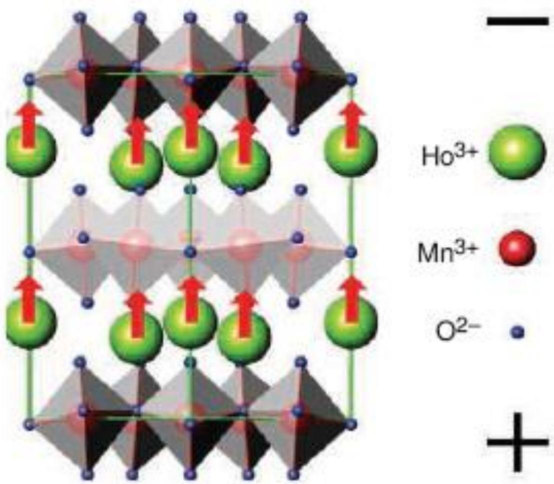
✓**Size of the cations:**

✓**Magnetism versus d-orbital Occupancy:** The existence of d-electrons on the B-site cations reduces the tendency of perovskite oxides to display the ferroelectricity.

✓**Structural distortion:** Ferroelectric materials must undergo a phase transition that does not have a center of symmetry (achieved in perovskite ferroelectrics). For a cation with certain d-orbital occupancy, the tendency to undergo a J-T distortion is strong and likely to be dominant structural effect. This subterfuges the non-centro symmetric structure.



Perovskite Structure
(A: Grey, B: Black, O: Blue)



Multiferroic $HoMnO_3$

Science 309, 391 (2005)

Two Phase composite multiferroics e.g. $PbZr_{1-x}Ti_xO_3$ and $Tb_{1-x}Dy_xFe_2$ have been successfully tried out. YMnO3 is a better candidate because it contains heavy and easily oxidized elements and it is free from elements such as Pb and Bi

Motivation

- Is it possible to observe multiferroic property in a spin frustrated material very near to room temperature?

- What is the microscopic origin of the coupling between electric and magnetic order in frustrated magnetic system?

- Are the bulk properties giving some kind of indication for the application of $Bi_2Fe_4O_9$?

- How doping will affect the ME coupling in pentagon spin frustrated $Bi_2Fe_4O_9$?

Experimental techniques used

Sample preparation
- Solid state reaction
- Sol gel

Crystal and magnetic structure
- X-ray diffraction
- Neutron diffraction

Surface morphology and compositional study
- Scanning electron microscopy
- Energy dispersive spectroscopy

Optical characterization
- UV-Visible spectroscopy
- Raman spectroscopy

Magnetic characterization
- SQUID

Magnetoelectric coupling study
- Magneto-dielectric study

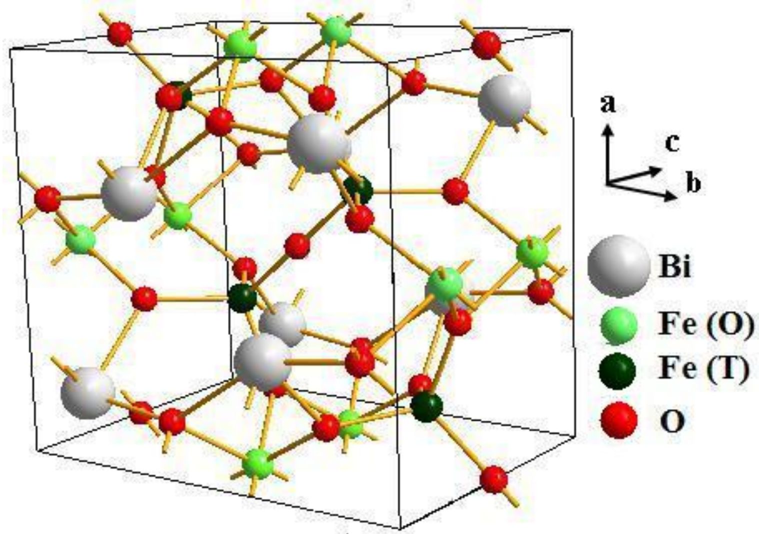
Thermodynamic measurement
- PPMS

Ferroelectric characterization
- PE measurement
- CV measurement

Crystal structure

- Orthorhombic structure
- Space group *Pbam*
- Two formula units per unit cell
- $T_N = (265 \pm 3)$ K
- Magnetic moment = 4.95 μ_B, compared with the value of 5 μ_B for the Fe^{3+} free ion.
- There are four octahedral Fe ions on the sides of the cell and the remaining four tetrahedral Fe ions are in the interior.

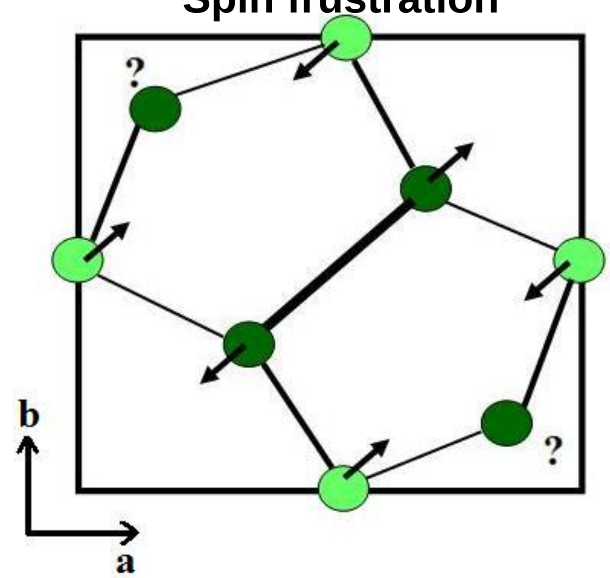
Crystal Structure



Sample preparation

- Polycrystalline samples of $Bi_2Fe_4O_9$ were prepared by conventional solid state reaction process at 850 °C at ambient pressure for 12 hours.
- $Bi_2O_3 + 2Fe_2O_3 \longrightarrow Bi_2Fe_4O_9$
- To ensure the stoichiometry, homogeneity and density of the pallets, the grinding and sintering process was repeated thrice.

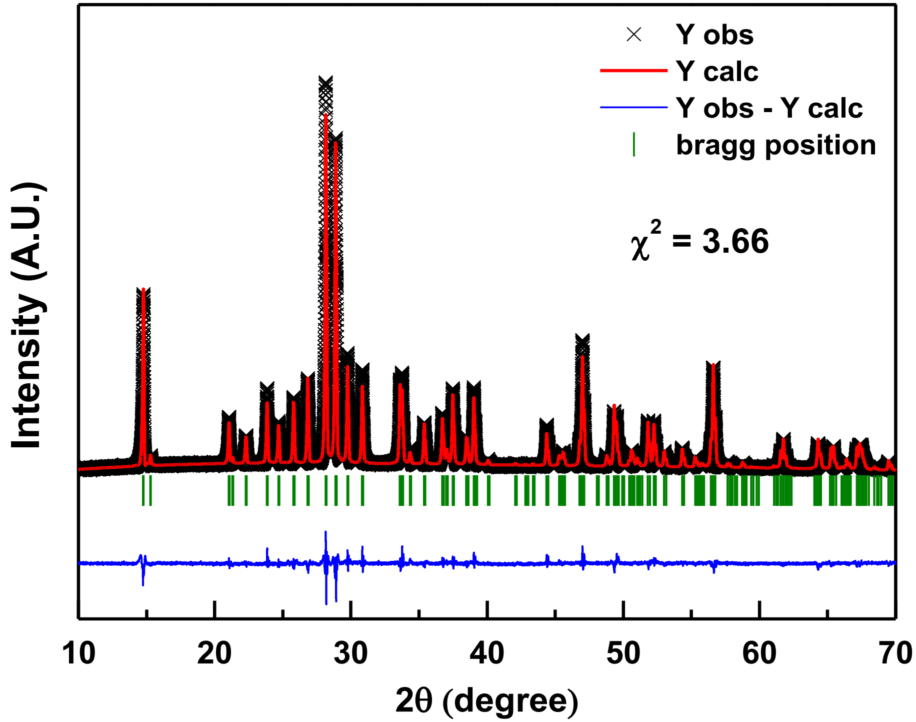
Spin frustration

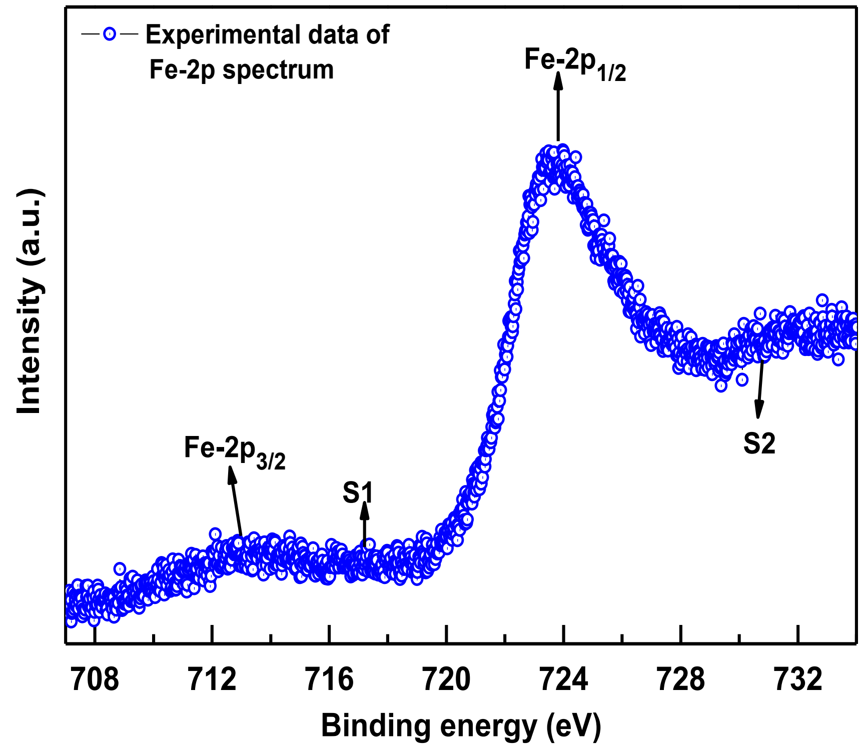


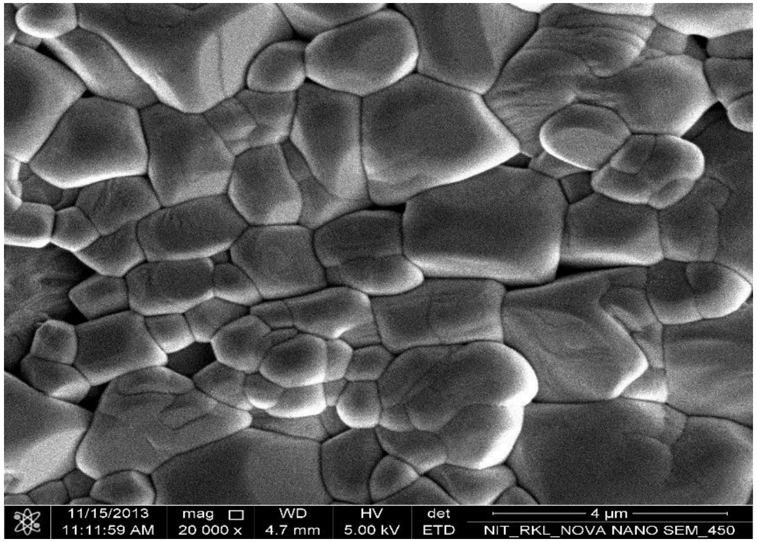
A. K. Singh *et al.*, Appl. Phys. Lett. **92**, 132910 (2008)

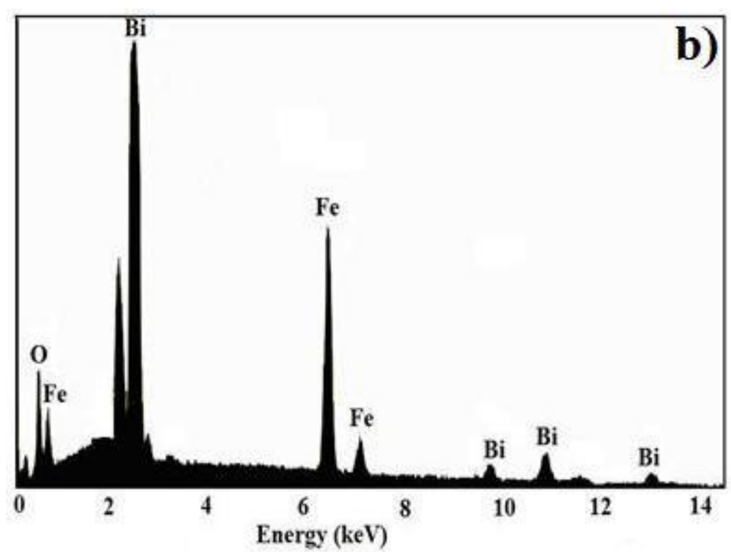
http://www.natureasia.com/asia-materials/highlight.php?id=244

XRD, FESEM, EDS and XPS Data

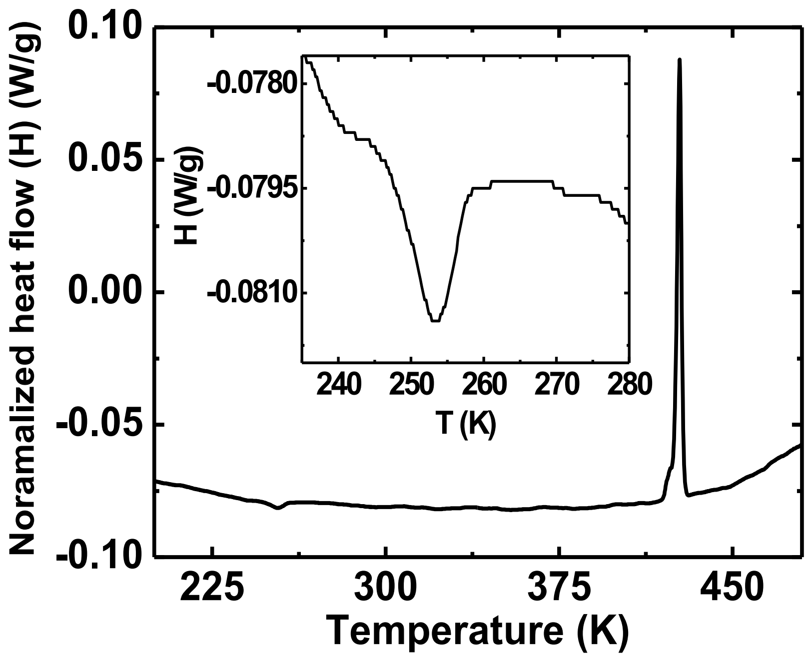


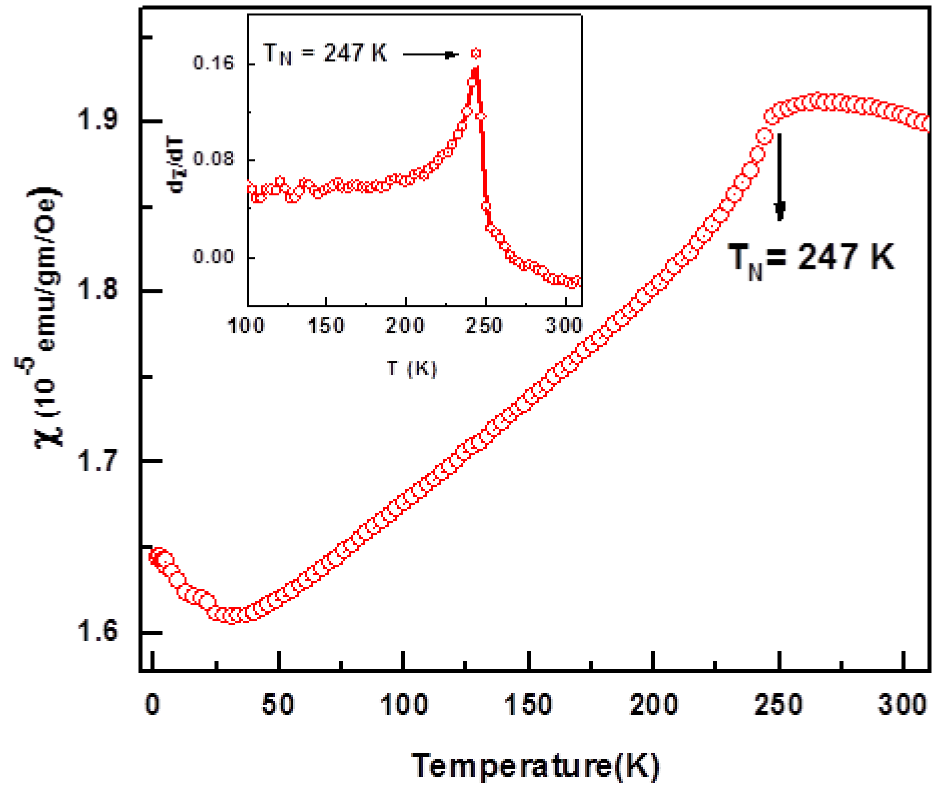


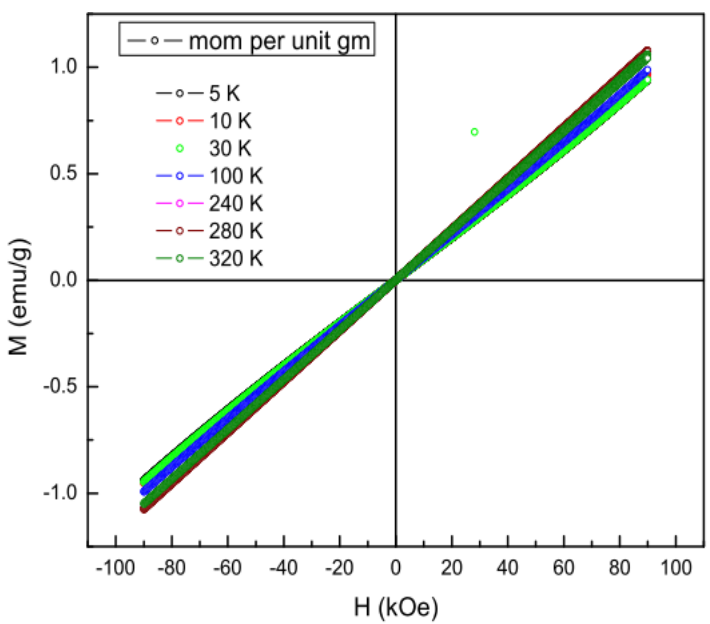




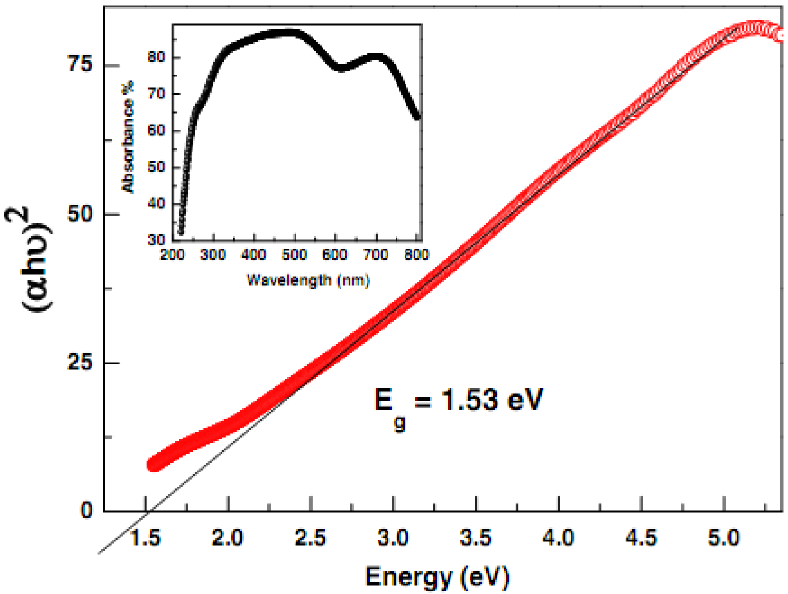
DSC, and SQUID Data

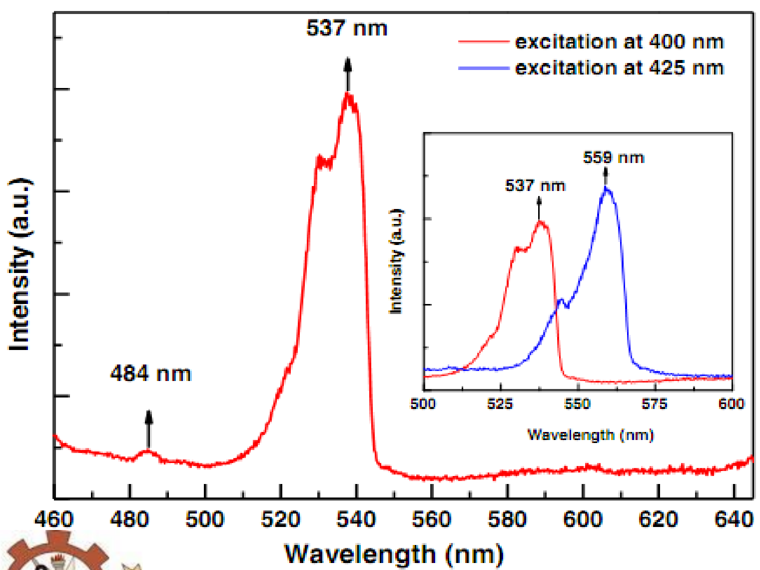


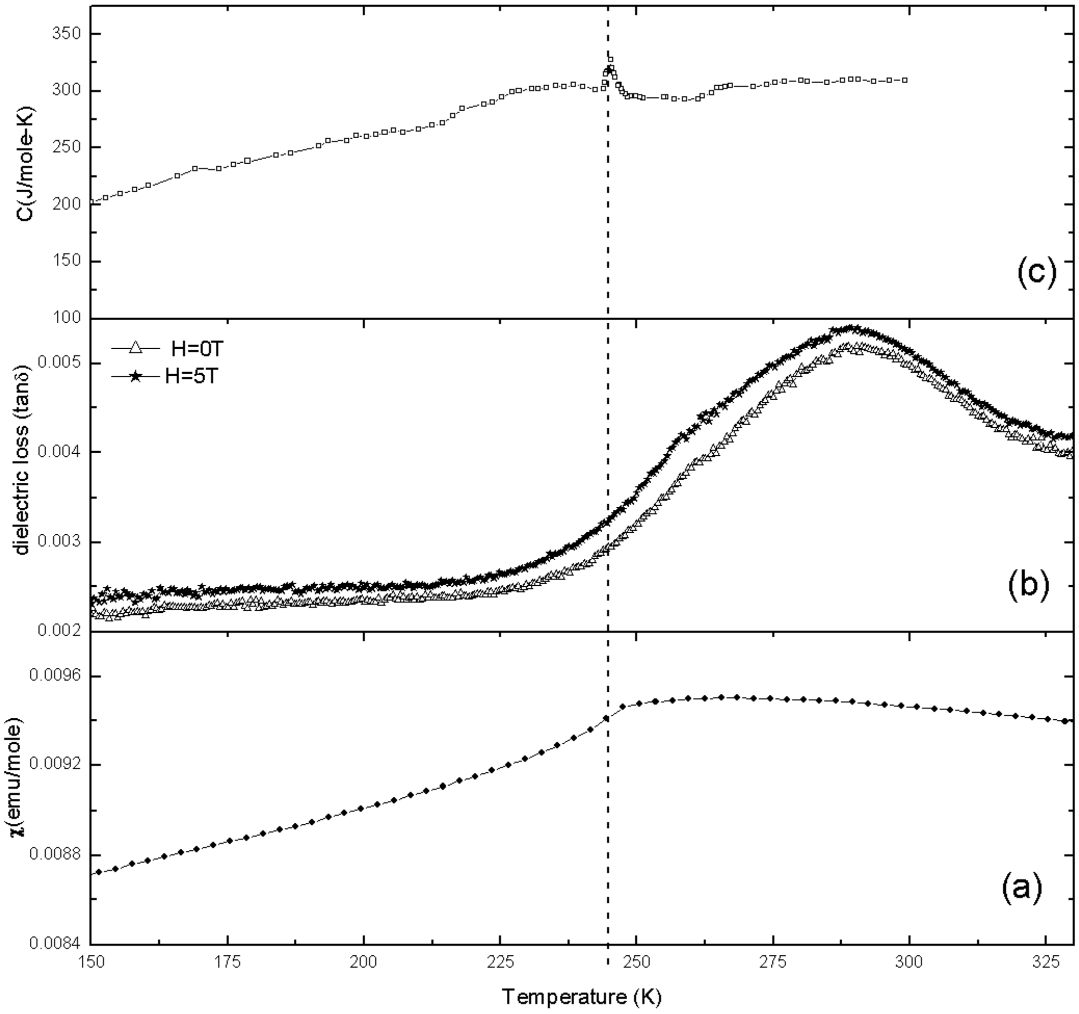




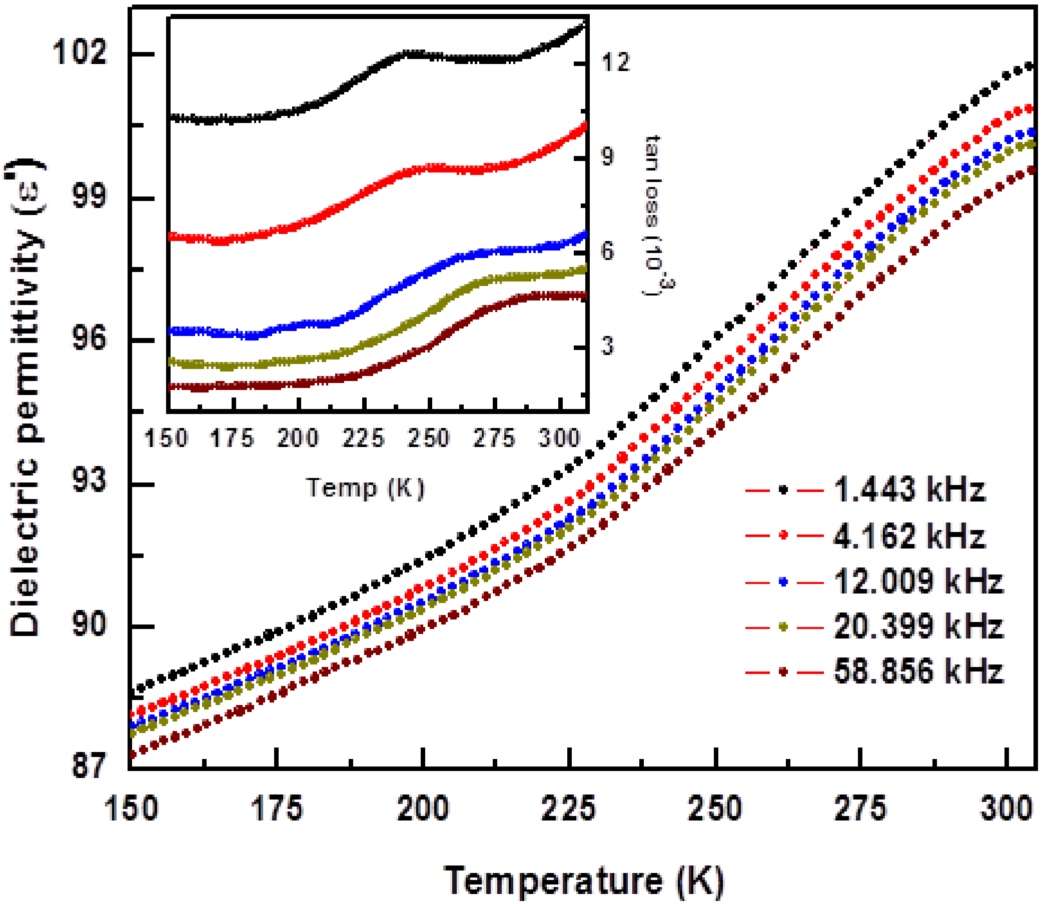
UV-visible spectroscopy and Heat capacity Data

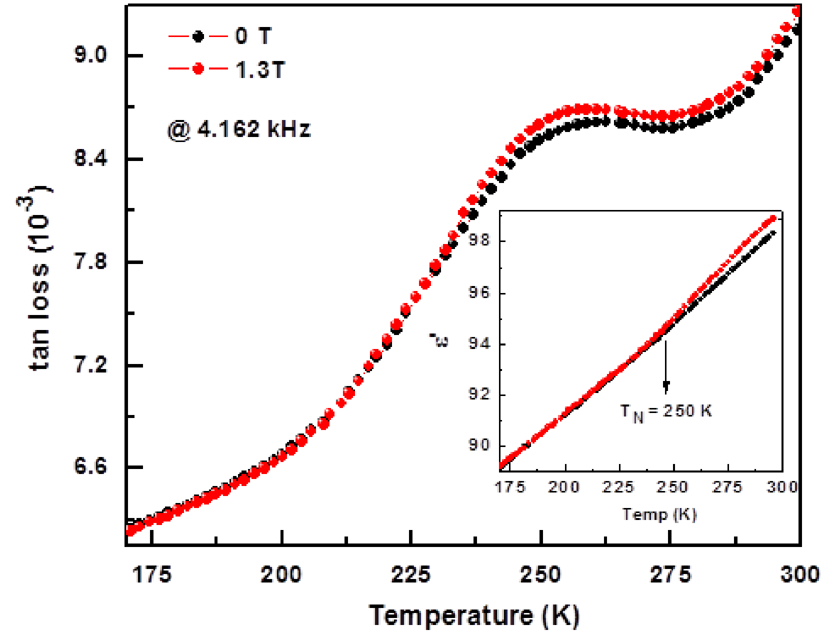


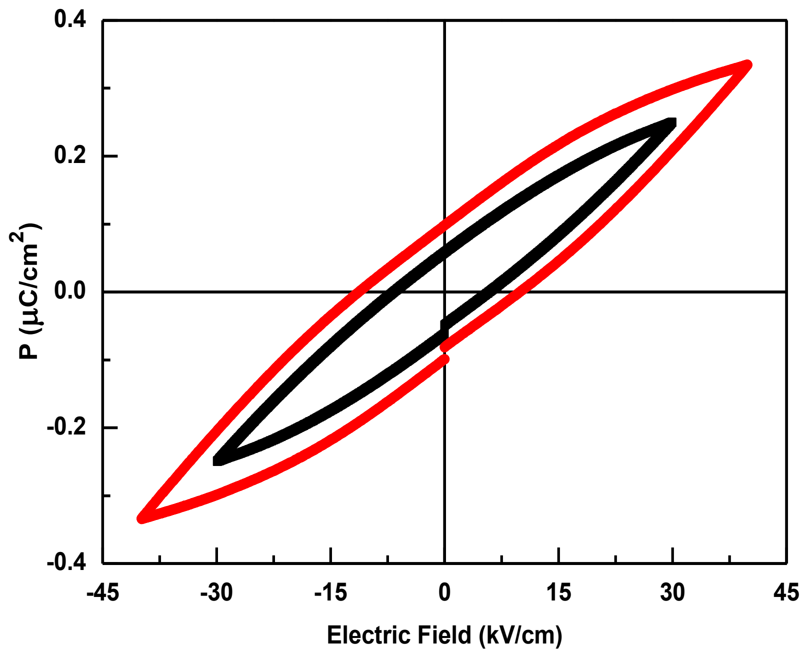




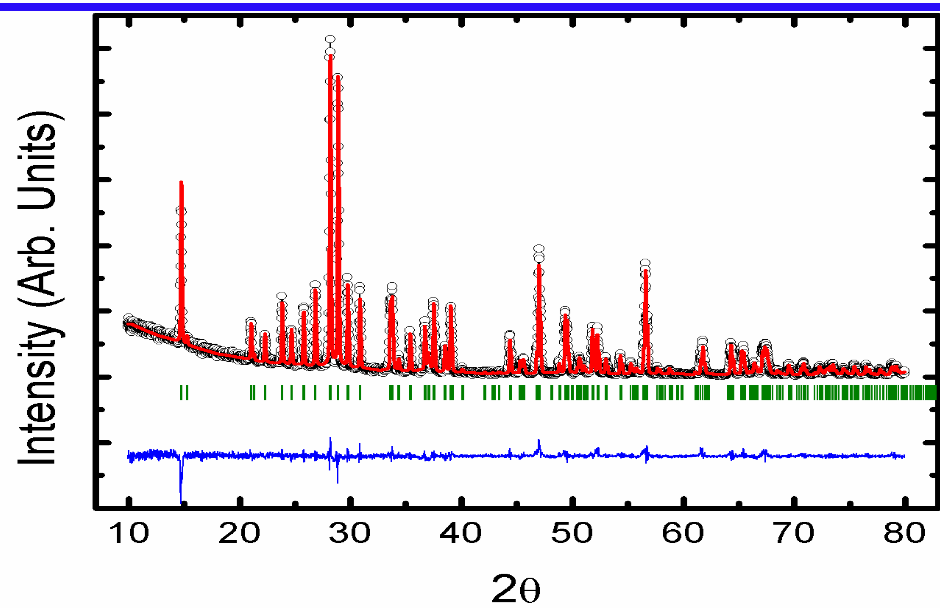
Dielectric, ME coupling, PE measurement

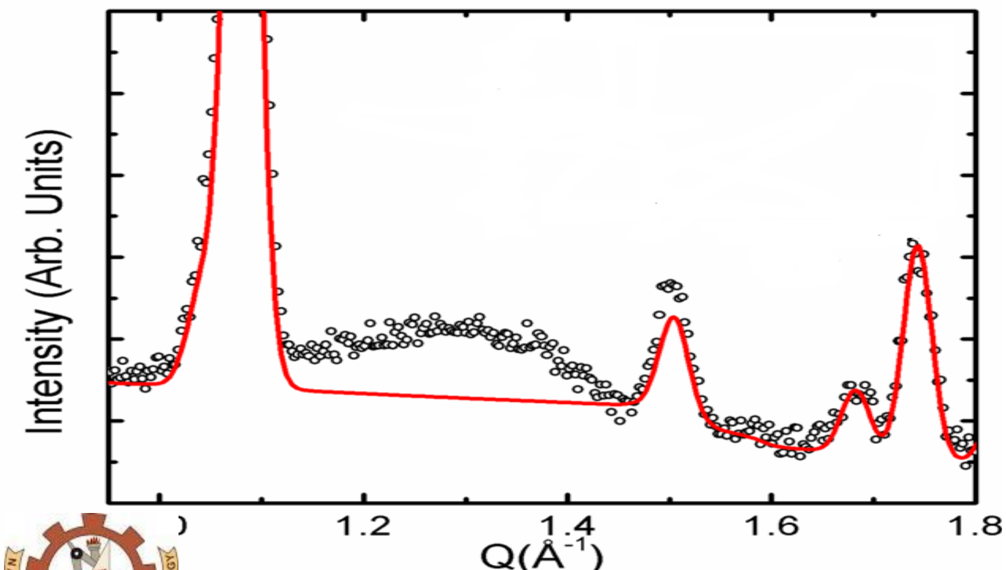


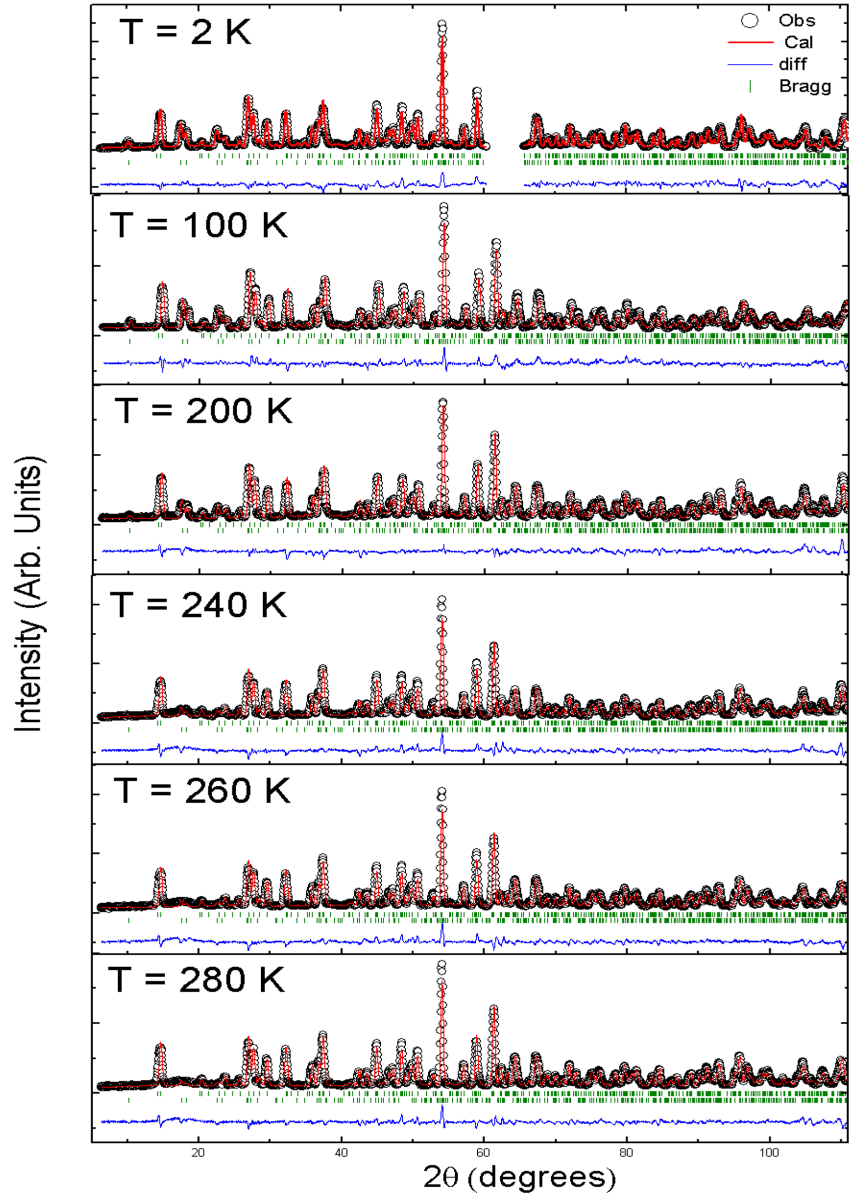




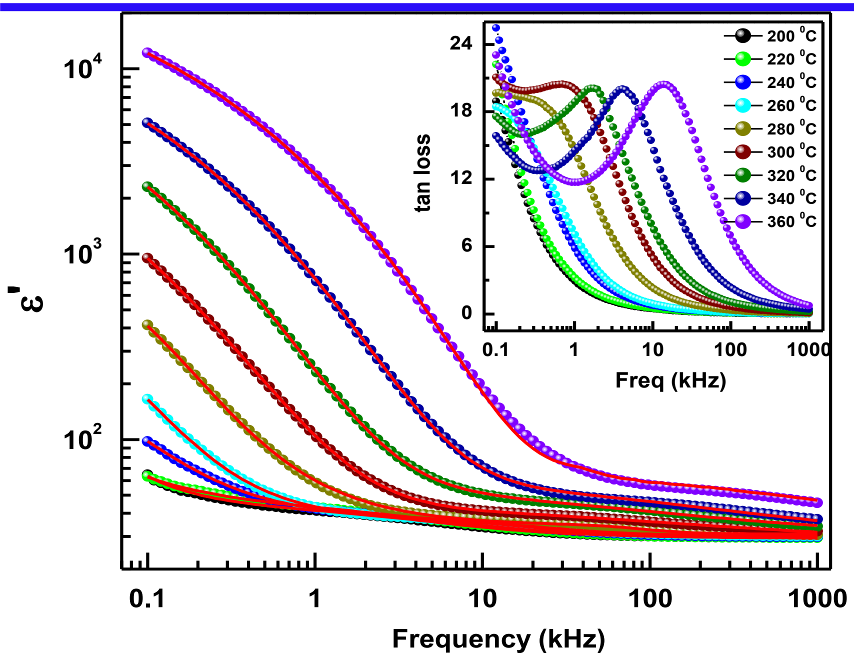
Neutron diffraction results

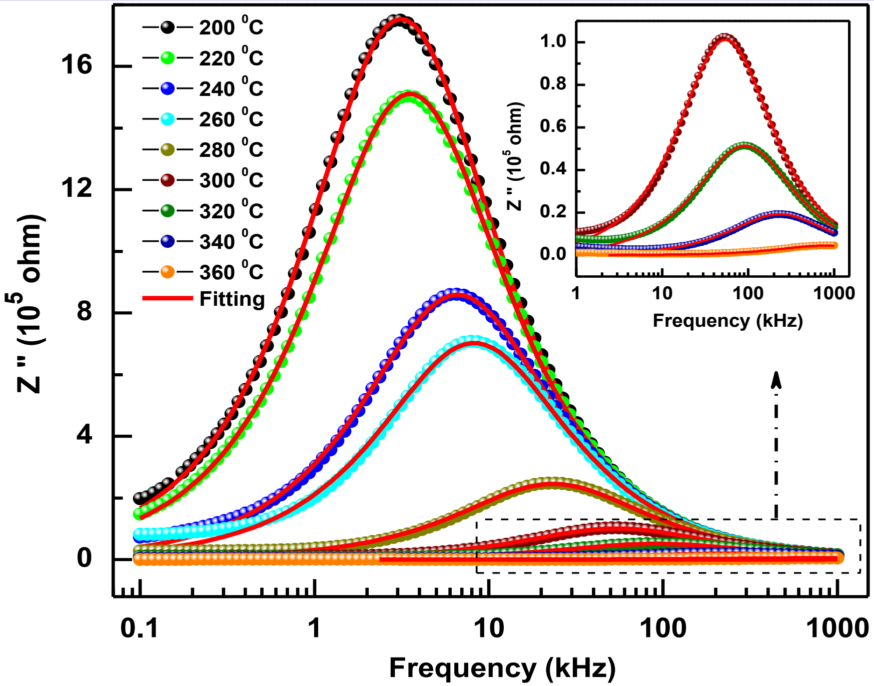


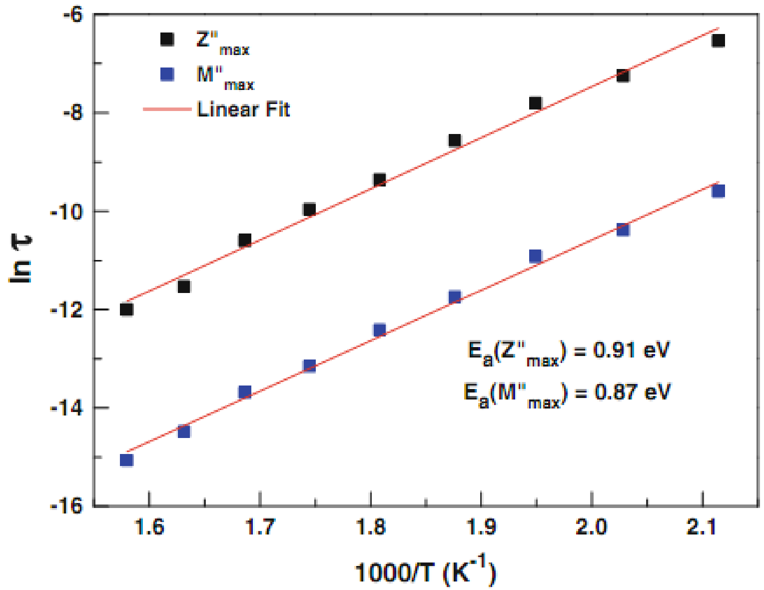


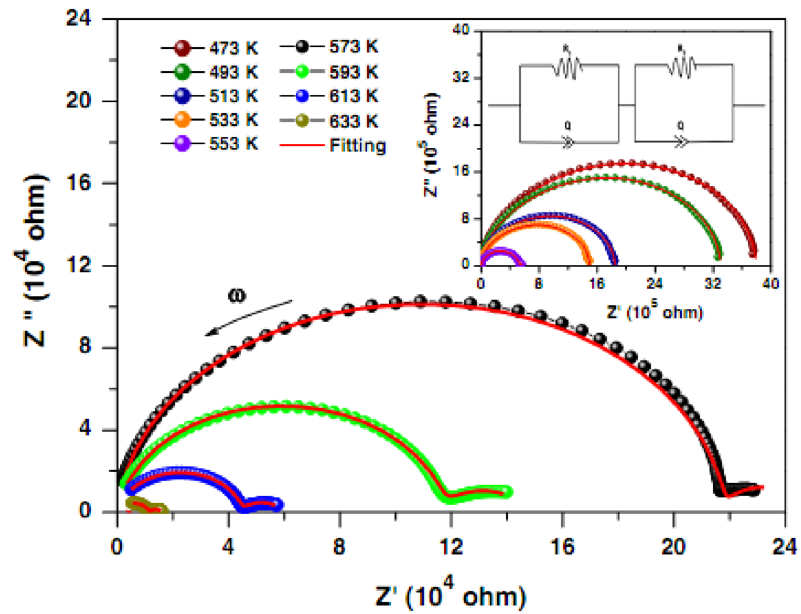


High temperature dielectric and conduction mechanism









A. K. Singh et al., J Mater Sci: Mater Electron, 2015.

Conclusion

- $Bi_2Fe_4O_9$ shows novel magnetoelectric property very near to room temperature.

- BFO has a great potential to be used as a magnetic field sensor as its ME coupling at room temperature is ~ 8% for 1.4 T magnetic field.

- Its semiconducting properties enables us to use this material for solar cell application.

- BFO can also be used as multiple state memory application.

References

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5. B. Sahu et al., AIP Conf. Proc. **1665**, 140043 (2015).
6. *S. R. Mohapatra et al., J Mater Sci: Mater Electron.* ***10****, 4203 (2015)***.**

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