Preface

Multiferroic materials are broader class of multifunctional materials which display simultaneously ferromagnetism, ferroelectricity, and ferroelasticity in single phased nature. In the present thesis work, a special focus has been made on multiferroic materials which interestingly demonstrate the presence of cross correlations between magnetic and electronic properties. Such materials have been considered to be potentially important ones for their uses in various applications. Keeping in view the significance and relevance of these materials, the entire thesis has therefore been presented in six chapters.

Chapter-I, documents clearly on essential basic information on nanomaterials with their properties towards understanding their importance in identifying newer materials. In the same chapter required theoretical aspects pertaining to certain multiferroic have been dealt with.

Chapter-11, describes the preparation of certain multiferroic nanomaterials (GdMnO₃, GdFeO₃ and BiFeO₃) based on chemical co-precipitation method. This chapter also elaborates on different characterization techniques employed in the analysis of multiferroic materials from the measurement of TG-DTA/DSC, XRD, HRSEM also with EDAX, FTIR, VSM, ferroelectric measurement (P-E measurement by Sawyer – Tower set up circuit) and PSM in understanding their thermal, structural, magnetic, electric and dielectric properties respectively. While understanding the procedures and tools involved in the present work, some relevant and basic research has been done in the initial stages that have resulted in publishing the following publications to ensure upon valid approach in this direction of work

i. B. Jaya Prakash & S. Buddhudu
   *Synthesis and analysis of LiNbO₃ ceramic powder by co-precipitation method*

ii. B. Jaya Prakash & S. Buddhudu
    *Synthesis and characterization of Mn³⁺:LiNbO₃ nanoparticles by co-precipitation method*
iii. B. Jaya Prakash, V.Naresh and S.Buddhudu,

*Synthesis and analysis of Li$_{0.3}$Mn$_{0.7}$NbO$_3$ nano ceramic powders by co-precipitation method*

*Int. Conf. on Thin films and Applications*

held at Sastra University, Thanjavur, March 15-17, 2012, P-72.

**Chapter-III**, reports on the results concerning thermal, structural, magnetic and electrical properties of GdMnO$_3$ nanoparticles. XRD analysis of the GdMnO$_3$ nanoparticles having orthorhombic crystal structure. From TG curve, thermal decomposition processes is analyzed and during the thermal process energy change takes place in sample and thus its crystalline nature becomes confirmed based on a exothermic peak of DTA profile at 740 C. The multiferroic properties of GdMnO$_3$ nanoparticles have been understood from the measurement of the M-H hysteresis loop as well as P-E hysteresis loop. From M-H hysteresis loop at different temperatures revealing the existence of antiferromagnetism at lower temperature below 46K and above this temperature it becomes paramagnetic and it is conformed from measurement of Zero field-cooled (ZFC) and field-cooled (FC) magnetizations and its numerical derivative. P-E hysteresis loop of GdMnO$_3$ nanoparticles shows ferroelectric hysteresis loop at room temperature. Ferroelectric phase transition of the sample has been observed from the measurement of dielectric constant with respect to temperature and also evaluated ac and dc conductivities of GdMnO$_3$ nanoparticles. These results have earlier been published as detailed below:

i. B. Jaya Prakash, K. Naveen Kumar & S. Buddhudu

*Thermal, magnetic and electrical properties of multiferroic GdMnO$_3$ nano particles by a co-Precipitation method*


ii. B. Jaya Prakash & S. Buddhudu

*Magneto-dielectric properties of multiferroic GdMnO$_3$ nanoparticles*

*Int. Conf. on Recent Advances in Composite Materials (ICRACM-2013), February 18-21, 2013, Goa, P-117.

**Chapter-IV**, brings out the results relating to the thermal, structural, magnetic and electrical properties of GdFeO$_3$ nanoparticles. From TG curve, thermal decomposition processes have been analyzed and during this thermal process, energy change in sample is noticed and hence its crystalline nature becomes confirmed from the observed exothermic peak of DTA profile at 540 C. The
multiferroic properties of GdFeO$_3$ nanoparticles have been understood from the measurement of the M-H hysteresis loop as well as P-E hysteresis loop. From M-H hysteresis loop at different temperatures revealing existence of antiferromagnetism at lower temperature below 130 K and above this temperature it becomes paramagnetic and it is confirmed from measurement of Zero Field-Cooled (ZFC) and field-cooled (FC) magnetizations and its numerical derivative. P-E hysteresis loop of GdFeO$_3$ nanoparticles shows ferroelectric hysteresis loop at room temperature. Ferroelectric phase transition of the sample has been observed from the measurement of dielectric constant with respect to temperature and also evaluated ac and dc conductivities of GdFeO$_3$ nanoparticles and these results have earlier been presented in a national conference.

B. Jaya Prakash and S. Buddhudu

*Studies on structural, magnetic and electrical properties of nanosized GdFeO$_3$ multiferroic ceramic powders*

*Nat. Conf. on Adv. Mater. & Appl. (NCAMA-2013)*

April 4-5, 2013 held at NIT, Tiruchirappalli, P-117.

**Chapter-V**, presents the results pertaining to the thermal, structural, magnetic and electrical properties of BiFeO$_3$ nanoparticles. XRD analysis of the BiFeO$_3$ nanoparticles has revealed a rhombohedral crystal structure. From TG curve, thermal decomposition processes has clearly been noticed during the thermal process possible energy changes take place in the sample and hence its crystalline nature is confirmed from an exothermic peak at 465 C in the DTA profile. The multiferroic properties of BiFeO$_3$ nanoparticles have been investigated from the measured M-H hysteresis loop also from the P-E hysteresis loop. M-H hysteresis loop reveals the existence of a weak ferromagnetism at room temperature, whereas the P-E hysteresis loop of BiFeO$_3$ nanoparticles demonstrates a ferroelectric nature at room temperature. Ferroelectric phase transition of the sample has been observed from the measurement of dielectric constant with respect to temperature. Thus the values of ac and dc conductivities of BiFeO$_3$ nanoparticles have successfully been evaluated. The results of this chapter have recently been communicated to the following journal:
Chapter VI, gives a comprehensive summary on the important results of the work that is carried out in the present thesis using three multiferroic materials like GdMnO₃, GdFeO₃ & BiFeO₃ nanoparticles. The following table presents magnetic and electrical properties of multiferroic materials. Besides that their XRD analyses have revealed that two of those samples GdMnO₃ & GdFeO₃ are in orthorhombic and whereas BiFeO₃ sample in rhombohedral in structures based on JCPDS: 250337, 74-1476 and 86-1518 respectively.

<table>
<thead>
<tr>
<th>Multiferroic Materials</th>
<th>Magnetic Properties</th>
<th>Electrical Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ferroelectric property</td>
</tr>
<tr>
<td>GdMnO₃</td>
<td>Antiferromagnetism Below 65 K</td>
<td>Ferroelectric hysteresis loop at 300 K</td>
</tr>
<tr>
<td>GdFeO₃</td>
<td>Antiferromagnetism Below 657 K</td>
<td>Ferroelectric hysteresis loop at 300 K</td>
</tr>
<tr>
<td>BiFeO₃</td>
<td>Weak Ferromagnetism at 300 K</td>
<td>Ferroelectric hysteresis loop at 300 K</td>
</tr>
</tbody>
</table>

Thesis results have therefore been presented in a national workshop and also in an enhanced form in the forthcoming ISC national conference as detailed below:

i. B. Jaya Prakash, V. Naresh & S. Buddhudu
*Studies on structural, thermal, electrical and magnetic properties of certain multiferroic nanomaterials synthesized by co-precipitation method*  

ii. B. Jaya Prakash & S. Buddhudu,
*Studies on structural, thermal, multiferroic properties of GdMnO₃, GdFeO₃ & BiFeO₃ nanomaterials.*  
101st Indian Science Congress (ISC), to be held during 3-7 February, 2014, at Jammu University, Jammu.