Chapter 7

Conclusions and future plan

7.1 Overview

In this thesis, studies of structural, morphological, compositional, optical, electronic, and magnetic properties of noncollinear magnetic materials covering the most attractive features like multi-domain q-structures, magnetic skyrmions, and spin reorientations in binary metal dihalide, cubic chiral magnet, and transition metal doped rare earth orthoferrites are presented. This chapter summarizes the results and possible future extension of the work.

7.2 $NiBr_2$

The triangular spin lattice of $NiBr_2$ is a canonical example of frustrated helimagnet that shows a collinear commensurate antiferromagnetic to an incommensurate spin helix phase transition on cooling. Herein, studies of self-flux grown $NiBr_2$ single crystal by neutron diffraction and low temperature magnetization measurements at fields up to 14 T were manifested. Experimental findings enable to deduce the driving force responsible for the spin spiral ordering. The neutron diffraction data reveals satellite peaks-representing characteristic features of an incommensurate magnetic state. The satellites develop symmetrically below T_N = 44.0(1) K replacing the main magnetic reflections. Interestingly, a field-induced incommensurate to commensurate spin phase transition has been succesfully demonstrated that enforces spin helix to restore the high temperature compensated antiferromagnetic structure. This reorientation can be described by a spin-flop in the *(a–b)* basal plane of a triangular spin lattice system. The findings offer a novel way for spin helix control of incommensurate phases, having immense scientific and technological implications in the next-generation data storage devices.

7.3 Cd^{2+}-Cu_2OSeO_3

The past decade has seen a significant uptick in research interest to study the materials that can host magnetic skyrmion lattices. The curiosity of such materials is mainly driven by the technological applications of emergent skyrmion lattices that manifest a whirlpool-like spins arrangement. Insulating Cu_2OSeO_3 reported to host magnetic skyrmion lattices below 60 K and considered as a potential candidate for exploring this new phase of materials. A new synthesis process to grow the Cd^{2+}-substituted Cu_2OSeO_3 nanocrystallites with variable sizes ranging over 50–200 nm were demonstrated. The proposed method consists of only a single-step heat treatment of 12 h, which is cost-effective than the routine solid-state process that requires a rigorous 15–20 days of heat treatment. By employing X-ray diffraction (XRD), transmission electron microscopy (TEM), energy dispersive X-ray analysis (EDX), X-ray photoelectron spectroscopy (XPS), and isothermal magnetization (M-T) measurements, and a comparative investigation of the structural, electronic and magnetic properties of pristine and Cd^{2+}-substituted Cu_2OSeO_3 nanocrystallites samples was conducted. As non-magnetic substitution can alter the fundamental magnetic interactions, therefore, Cd^{2+}-Cu_2OSeO_3 nanocrystallites offer a new methodology to control the magnetic skyrmion phases and its stability.

7.4 Mn-$SmFeO_3$

$SmFeO_3$ is the one of the prototypes of $ReFeO_3$ (where, Re corresponds to rare-earth ions), which is family of the canted antiferromagnet (or weak ferromagnet) and shows multiple phase transitions on cooling. The powder $SmFe_{0.75}Mn_{0.25}O_3$ (SFMO) nanocrystalline sample were synthesized by the conventional solid-state reaction route followed by optical float zone technique to obtained good quality of single crystals. Rietveld refinement of the X-ray diffraction (XRD) and Laue diffraction pattern of the materials show crystallization in the orthorhombic structure with Pbnm space group. The experimental observation demonstrates the microscopic features at nuclear lenght scale of magnetic phase transitions in offset of SRTs in $SmFe_{3/4}Mn_{1/4}O_3$. Mn-substitution in $SmFeO_3$ leads a new spin-reorientation transition ($\Gamma_2 \rightarrow \Gamma_1$) at 150-180 K and significant suppression of the second order $\Gamma_4 \rightarrow \Gamma_2$ transition from the 480 to 390 K observed in $SmFeO_3$. The origin of SRTs is attributed to spin-phonon coupling at bulk, and at the nuclear lenght scale quantitative information is observed via the temperature dependent hyper-fine interactions of the iron nuclei in the orthoferrite using X-ray absorption spectroscopy. The experimental findings pave the way for accessing the atomic scale details to understand the multi-functional behavior of $SmFe_{3/4}Mn_{1/4}O_3$.

7.5 Future scope of the work

These compounds are the best series of materials to explore the precursor phases of skyrmions, spin reorientations and improper multiferroicity. This thesis demonstrate the structural, morphological, compositional, optical, electronic, and magnetic properties of binary metal dihalide, cubic chiral magnet, and transition metal doped rare-earth orthoferrites in the view of noncollinear magnetic systems. In future, we have planned to visulise and manipulate these nano length scale magnetic texture in these materials. These materials can be used as a target to grow the thin films and to study their various properties. The structural and magnetic properties in thin film-form can be compared with the results obtained in this thesis.

In addition, it would be also interesting to fabricate the thin films on different substrates using pulsed laser deposition and sputtering technique to study their comparative effects on the structural, electronic transport and magnetic properties in the context of film thickness, strain, surface roughness, substrate temperature, ambient gas pressure of chamber etc.