Chapter 7

Conclusion

Major highlights of the present investigation are summarized in this chapter, outlining the potential utility of magnetic nanowires/nanotubes and hybrid magnetic nanostructures with MWCNTs. Several advantages of template-assisted approach over other available routes along with some of their limitations are also dealt with in this chapter. Moreover, the prospective applications of such high aspect ratio magnetic nanostructures formed in the absence of chemical modifications of porous nano structure or surface passivation agents in various fields are also reviewed. The method of synthesis of multifunctional magnetic nanostructures has been extended to the fabrication of a multiferroic material using template assisted deposition. The initial results of this work are also briefly discussed in this chapter.
Chapter 7

Investigating magnetic properties of matter on the nanoscale is a very active area in modern solid state physics. Exciting phenomena, like inter layer exchange coupling or the giant magneto resistance occurs in low dimensional systems where characteristic length scales such as magnetic exchange lengths, become relevant. Nanomagnetism is of utmost importance to current technological developments. The dramatic increase in magnetic storage density over the last decade, various applications of miniaturized magnetic sensor devices based on the giant magneto resistance effect, and the development of spintronics, a new generation of computing technology, require a thorough understanding of magnetism at the nano meter scale.

Spintronics considers spin of an electron as additional degrees of freedom, which can be manipulated to obtain particular functionalities. Recent concepts for Spintronic logical elements discuss domain walls, which are intermediate region of spin inhomogeneity between two domains with opposite magnetization directions, in nano wired elements. Other magnetic nano scale systems that exhibit the large scale activities, both in fundamental and applied research are multilayers, oxides, nanoparticles, nanostructures, magnetic semiconductors, magneto caloric materials (MCE materials) and multiferroic materials. Several key questions in these systems depend on the dynamics of magnetization and the associated magnetic structures.

The fabrication and characterisation of 1-D magnetic nanostructures of uniform size and shape have importance in the current scenario of advanced research to design multifunctional nanostructures and various nanoelectronic devices. Nanowires and nanotubes of Ni and Co having high aspect ratio, high crystallinity and texturing were fabricated. They also exhibited high magnetic response and interesting temperature dependent magnetic properties. A very high magnetic dipolar interaction was identified among these magnetic nanowires and nanotubes and it can suitably tuned by
controlling the separation between them and it is very important in device fabrication and magnetic data storage. A very high coercivity Co NTs were fabricated for the first time using cobalt acetate as precursor. The elucidation of a general growth mechanism during template assisted potentiostatic electrodeposition was another milestone of the present thesis.

A mobility assisted growth mechanism was proposed for the growth of 1-D nanostructures during potentiostatic electrodeposition inside porous templates and its veracity has been tested using various porous templates and precursors. This growth mechanism has been utilised to design a novel multisegmented bi-metallic magnetic nanostructure, called Ni @ Co nanorods and this again opens the possibility designing other hybrid structures using template assisted electrodeposition. Moreover, tuning of magnetic properties can be successfully attained using these types of hybrid magnetic materials and it is an added advantage over other nanofabrication techniques, where the tunability is not as handy as it here.

Alumina templates are beneficial for shape controlled synthesis of not only high aspect nanostructures but also other non-spherical shapes without the assistance of any capping molecules/surfactants or any other foreign species. In perpendicular geometry of nanowires and nanotubes, GMR can be significantly larger than when current is in the film plane. Heterogeneous alloy films, which are of interest for their GMR, which is a promising property of high density storage media, have also been successfully prepared by electrodeposition. Extremely high aspect ratio (ratio of length to diameter), will make the demagnetizing field highly anisotropic; which is one of the desirable criteria for the achievement of perpendicular recording. Various magnetic alloys and heterostructures can be tested for their GMR and MCE performance and is reserved as a future prospective.
Hybrid magnetic materials with carbon nanotubes represent a novel class of smart materials where they can find immense technological and fundamental interest. Metal filling inside CNTs and the subsequent dragging of the metals is one of the active and cutting edge research area where we can fabricate more interesting carbon structures such as graphene. MWCNTs filled various magnetic nanostructures were synthesized and they also exhibited interesting magnetic properties. Ni and Co were electrodeposited inside MWCNTs using various precursors and interesting structures are obtained under different precursors. The mobility assisted growth mechanism has been successfully verified in the case of MWCNTs too.

An interesting co-axial nanostructure of MWCNTs with Co nanotubes has been fabricated using cobalt acetate as precursor for electrodeposition. This co-axial structure also found to exhibit very high longitudinal coercivity indicating the structure perfection and shape anisotropy of the nanostructure. Interesting applications of these nanostructures are also attempted to probe. Ni filled MWCNTs found to exhibit an enhanced microwave absorption capability when compared to Ni NWs and MWCNTs. This can be due to the increased metal-MWCNT interfaces and nanosized particle size of the Ni particles. MWCNTs were almost completely impregnated with aqueous ferrofluids of Iron Oxide using the principle of nanocapillarity.

The successful, complete filling of MWCNTs with magnetic materials like ferrofluid is being reported for the first time. The resulting nanostructure also found to exhibit interesting magnetic properties. Confined existence of superparamagnetic Iron Oxide nanoparticles inside MWCNTs leads to an anomalous enhancement in magnetisation with temperature. Origin of this anomalous magnetic property is supposed to be due to the increased magnetic interactions due to the confined existence and warrant
detailed investigations. The MWCNT-Superparamagnetic Iron Oxide system is identified as an excellent system for various bio-medical applications such as augmented drug delivery, cell separation, contrast enhancement agents in MRI, drug targeting and hyperthermia. Studies on the drug attachment and delivery, and therapeutical applications are highly promising and are proposed as future perspective.

Non-linear optics is another mature field of science and engineering and the synergy of non-linear optics with magnetism is thought to be a novel idea for the fabrication of various multifunctional nanostructures. The fabricated nanowires and nanotubes of Ni, Co and Ni @ Co nanorods and their hybrid structures with MWCNTs found to exhibit interesting non-linear optical properties. All these 1-D nanostructures were found to act as excellent non-linear optical limiters. Particularly, cobalt-in-carbon nanotube found to exhibit non-linear transmission behaviour where they exhibited inbetween behaviour of effective 3PA and effective 2PA. Moreover, optical limiting properties of MWCNTs were compared with that of metal nanotubes for the first time and such a comparison is more appropriate as both kind of system induce similar kind of geometrical distortion when an electromagnetic radiation falls on them.

The emulsions/dispersions of these one-dimensional structures can be made using various organic solutions and can be coated over sensitive optical devices and goggles to protect them from high intense lasers. Tunable non-linear optical limiter is one of the novel ideas in non-linear optics and not cherished yet. This kind of magnetic nanostructures in proper dispersion may fruitful this concept and much studies are needed on this topic. This also extends as a future prospective.

The importance of magnetic iron oxide is persists as high for a long time due to their extensive applications in particulate media and
biocompatibility. The concept of acicular iron oxide was emerged with their applications in storage media to reduce the signal to noise ratio. Acicular iron oxide nanoparticles were synthesized using starch as a complexing medium. Their magnetic and optical properties were compared with those of synthesized spherical nanoparticles. Interesting optical properties were identified and a strain induced band gap shift is observed in the case of acicular particles. The tuning of the aspect ratio can be achieved by controlling the processing parameters like concentration, pH, temperature, stirring speed etc and it opens a wide scope for future work. The acicularity dependent magnetic properties are highly intriguing and can find potential uses in various fields such as in particulate media. Role of complexing media such as starch/glycerol in controlling and tuning the aspect ratio is need to be subjected in to detailed investigation in order to synthesis complex nanostructures of magnetic as well as non-magnetic materials.

The expertise gained in the fabrication of magnetic nanostructures can be extended for the designing and the synthesis of other useful nanosystems. Multiferrocity is one of the emerging trend in material science research, where the same system exhibit ferromagnetic ordering as well as ferroelectric properties. Hybrid materials represent a novel class of materials where desirable properties of the individual systems are expected to dominate giving a multifunctional system. An attempt towards the realisation of hybrid materials based multiferroics is not taken anywhere and such a step will surely impact the future research and technology to a great extend. An initial step has been taken towards the realisation of a multiferroic material based on ferromagnetic nanotubes and ferroelectric nanotubes. The FESEM pictures of this hybrid structure are depicted in figure 7.1.
Studies on these hybrid nanostructures are in the initial stages and have a very high scope in the fundamental understanding of physics of multiferroic materials and increasing application demands due to their application potential.

Though template assisted synthesis is an ingenious technique comparing to other fabrication techniques, this technique also faces some drawbacks which need to be pointed out. Since the template is usually a thin membrane, it is difficult to scale-up the nanostructure and grow through this route to macroscopic quantities, although efforts in that direction are underway. Another lacuna of this technique is that the nanostructures synthesized through this template are often polycrystalline. Despite these shortcomings, template assisted electrodeposition is identified as a versatile technique and it will be worthwhile to employ this technique to fabricate other nanostructures resembling Ni@Co and Co-in-MWCNTs nanostructures.

Research is an eternal journey to unravel the mysteries of nature and every researcher contributes his might to the vast comity of
research. This contribution, though infinitesimally small, fits the old adage "Tiny drops of water makes a mighty ocean". This investigation must also be viewed from such a backdrop and this study and the subsequent contribution to the vast knowledge base will only form a nanocomponent in the mega canvass of Science.

However, this must be seen as yet another attempt to investigate the truth and the search for absolute truth goes on and on. It is often said that what remains constant in the universe is 'change'. Physicists are always looking for these 'changes' which would help modify their understanding of the nature and mould new concepts.

Finally, as the eastern philosophy goes, even if you have infinity as denominator the net 'result' is nothingness but it is ancient India which gave a definite value to this 'nothingness'. So nothingness is also something and very significant.