PREFACE

Magnetism and magnetic materials have been playing a lead role in the day to day life of human beings. The human kind owes its gratitude to the ‘lodestone’ meaning ‘leading stone’ which lead to the discovery of nations and the onset of modern civilizations. If it was William Gilbert, who first stated that ‘earth was a giant magnet’, then it was the turn of Faraday who correlated electricity and magnetism. Magnetic materials find innumerable applications in the form of inductors, read and write heads, motors, storage devices, magnetic resonance imaging and fusion reactors. Now the industry of magnetic materials has almost surpassed the semiconductor industry and this speaks volumes about its importance. Extensive research is being carried out by scientists and engineers to remove obsolescence and invent new devices. Though magnetism can be categorized based on the response of an applied magnetic field in to diamagnetic, paramagnetic, ferromagnetic, ferrimagnetic and antiferromagnetic; it is ferrimagnetic, ferromagnetic and antiferromagnetic materials which have potential applications. The present thesis focusses on these materials, their composite structures and different ways and means to modify their properties for useful applications.

In the past, metals like Fe, Ni and Co were sought after for various applications though iron was in the forefront because of its cost effectiveness and abundance. Later, alloys based on Fe and Ni were increasingly employed. They were used in magnetic heads and in inductors. Ferrites entered the arena and subsequently most of the newer applications were based on ferrites, a ferrimagnetic material, whose composition can be tuned to tailor the magnetic properties. In the late 1950s a new class of magnetic material emerged on the magnetic horizon and they were fondly known as metallic glasses. They are well
known for their soft magnetic properties. They were synthesized in the form of melt spun ribbons and are amorphous in nature and they are projected to replace the crystalline counterparts.

Metallic glasses are alloys of transition elements and metalloids and have attracted the attention of technologists owing to their superlative soft magnetic properties compared to other conventional crystalline materials. The transition elements like Fe, Co, Ni imparts magnetic properties, while metalloids like B and Si aid in amorphisation and Mo and Nb act as grain growth inhibitors. Nanocrystallinity can be induced in these alloys by thermal annealing and this improvises the soft magnetic properties. The nanocrystalline thin films are highly sought after for read and write heads and sensors. Metallic glass having a composition of Fe$_{40}$Ni$_{38}$Mo$_{4}$B$_{18}$ exhibits high saturation magnetisation, high Curie temperature and low anisotropy and crystallizes at 400$^\circ$C. The bulk properties of these alloys are well studied; however studies on thin films are rare in literature. Earlier investigations carried out in this laboratory on thin film forms of these alloys by employing vacuum evaporation yielded films with excellent magnetic properties; however the target and the film composition were at variance. Retaining the composition of the target in the film as well is necessary as this influences the magnetic properties substantially.

Preparation of thin films based on FeNiMoB incorporating the target elements and modification of its properties by various techniques is interesting as this system can act as an ideal template to study the role of target element, crystallinity and surface morphology on the magnetic properties. Fabrication of thin films by Radio Frequency (RF) sputtering is an ideal alternative and this forms part of the objective of this study. Moreover, a study on such thin film
forms will be a prelude for magnetic MEMS (Micro Electro Mechanical Systems).

Zinc ferrite is a normal spinel and known for its antiferromagnetic properties with a Neel temperature of 10K. However anomalous results are reported in the literature for nano zinc ferrite. In spite of the continued efforts by researchers, a conclusive explanation for such a behaviour is still elusive. The properties of zinc ferrite are highly dependent on the synthesis method. Zinc ferrite is purported to be an antiferromagnet and exhibits size effects on its magnetic properties and can exhibit ferrimagnetism at room temperature. These anomalies make zinc ferrite standout among other spinels. Most of the studies on zinc ferrite thin films lack high magnetisation at room temperature. A thin film form of zinc ferrite with appreciable saturation magnetisation will be a good candidate for fundamental research as well as for applications.

Exchange bias effect is the phenomenon wherein the spins of ferromagnet are pinned by the antiferromagnetic spins on field cooling below the Neel temperature of the antiferromagnet. As a result the hysteresis loop is shifted along the field axis accompanied by loop widening and shift in magnetisation direction. These kind of structures are highly desirable in spin valves and magnetic tunnel junctions. Theoretical and experimental studies have been done widely on the field of exchange bias, still technologists look for novel materials and techniques to control the exchange bias. Earlier exchange bias studies were mainly on ferromagnetic-antiferromagnetic system; but recently it has been reported that ferromagnetic-spin glass, ferrimagnetic-antiferromagnetic and even soft-hard magnetic systems can exhibit exchange bias. A bilayer system of FeNiMoB-zinc ferrite can exhibit exchange bias and is one of the main themes of this thesis. The modification of exchange bias by various techniques is also important.
Once we have the desired film, the next question is how can we improve or tailor the properties. Usually thermal annealing is employed which can alter the grain size and thus can change the magnetic properties. The effect of thermal annealing on films of FeNiMoB, zinc ferrite and their bilayer structure is being investigated.

Another technique to modify the material properties is by subjecting them to ion beam irradiation. Ion beams can be employed for synthesis, modifications and characterization of materials. When ions traverse through a material, they can impart their energy and momentum to the material. Depending on the energy of ions two regimes can be defined viz, nuclear energy regime (few KeV) and electronic energy regime (> few MeV). Swift heavy ion (SHI) irradiation can alter magnetic properties of bulk materials as well as thin films. The magnetic properties of thin films depends on a range of factors like composition, crystallinity, crystal structure, anisotropies-magneto-crystalline, surface and interface roughness, domain structure. By tailoring any of the above properties the magnetic properties can be modified.

Of the various factors affecting magnetic properties, inducing crystallinity seems to be a promising way to alter the magnetic characteristics due to the ease by which a material can be crystallised. Crystallization can be realised by thermal annealing whereas amorphisation can be induced in the material by SHI irradiation. Irradiation in crystalline materials results in creation of amorphous tracks embedded in the residual crystalline matrix. Ion irradiation can also result in ion beam mixing at the interface of two layers. Such investigations are of paramount importance in modifying the interfaces which will have a positive bearing on the exchange bias. Spinel structures are susceptible to track formation.
The track formation and the resulting changes in room temperature and low
temperature magnetic properties as a result of ion irradiation will be studied.

The exchange bias depends on the ferromagnet-antiferromagnet interface.
Ion beams can create defects as well as result in interface mixing in a bilayer
structure. The modification of exchange bias and the resultant exchange field can
be probed by ion irradiation. Ion beam irradiation induced modification of
exchange bias in FeNiMoB– zinc ferrite bilayer structure is examined in the
present thesis.

The effect of swift heavy ion irradiation and thermal annealing on the
structural, topographical and magnetic properties of FeNiMoB– zinc ferrite thin
films are of major concern in the present thesis.

The main objectives of the present study are the following:

1. To replicate the exact composition of Fe$_{40}$Ni$_{38}$Mo$_4$B$_{18}$ in their thin film
   forms by RF sputtering.
2. To study the effect of thermal annealing on the structural and magnetic
   properties of RF sputtered FeNiMoB thin films.
3. To tailor magnetic characteristics of FeNiMoB thin films by swift heavy
   ion irradiation.
4. To prepare zinc ferrite thin films by RF sputtering and detailed
   investigation of the mechanism responsible for magnetism in thin films.
5. To create amorphous tracks in zinc ferrite thin films by swift heavy ion
   irradiation.
6. To prepare exchange biased FeNiMoB – zinc ferrite bilayer film
7. To study the modification of exchange bias in FeNiMoB – zinc ferrite bilayer films by Swift heavy ion irradiation.

The proposed thesis is entitled “Swift Heavy Ion Irradiation and Thermal Annealing Induced Modification of Structural, Topographical and Magnetic Properties in Monolayer and Bilayer Films Based on FeNiMoB and Zinc Ferrite” and consists of eight chapters.

Chapter 1 gives an introduction to magnetism in general and ferromagnetism and antiferromagnetism in particular. The physics behind exchange bias effect and ion interaction in materials is dealt with in this chapter.

The preparation methods and experimental techniques used for the present study are described in chapter 2.

The thermal annealing effects on structural, topographical and magnetic properties of FeNiMoB films prepared by RF sputtering are presented in chapter 3.

Chapter 4 deals with swift heavy ion irradiation on RF sputtered FeNiMoB films with a view to enhancing the soft magnetic properties.

Chapter 5 describes preparation of zinc ferrite thin films by RF sputtering and the room temperature and low temperature magnetic ordering in these films. Effect of annealing is also one of the themes of this chapter.

The amorphisation and modification of properties in zinc ferrite films by swift heavy ion irradiation is covered in chapter 6.

Chapter 7 explains the exchange bias studies in FeNiMoB–zinc ferrite bilayer and its modification by thermal annealing and swift heavy ion irradiation. It was inferred that on ion irradiation, exchange bias greatly enhanced.
Finally conclusions of the research work and future outlook is presented in chapter 8.

PEER REVIEWED PUBLICATIONS:


CONFERENCE PROCEEDINGS


3. Effect of substrate temperature on the structural, topographical and magnetic properties of zinc ferrite thin films, Lisha Raghavan, Hysen Thomas, Geetha P,
M R Anantharaman, ISAS National conference on Advanced Technologies for Material Processing and Diagnostics (Third Best Poster Prize)

4. Tailoring topographical and magnetic properties of zinc ferrite thin films by 100 MeV Ag7+ ion irradiation, Lisha R, Hysen T, Geetha P, Shareef M, Shamlath A, Sunil Ojha, Indra Sulaniya, D K Avasthi, M R Anantharaman, Accepted for Poster presentation for International conference on Magnetic Materials and applications, ICMagMA 2014, (Best Poster Prize)

5. Ion Irradiation: A versatile tool for material modification, Lisha Raghavan, Hysen Thomas, Geetha P, M R Anantharaman, National seminar on Current trends in material science 2014 (Oral presentation)

6. Ion Irradiation induced modification of materials, Lisha Raghavan, Hysen Thomas, Geetha P, M R Anantharaman, National Seminar on Frontiers of Nanotechnology 2014 (Oral presentation)


