# Chapter 5

## Conclusions and Future Scope

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## 5.1 Conclusions

The work described in this thesis is based on the magnetic properties of two materials RE-TM CoTbNi and FePtCo ternary alloy thin films. Both materials exhibit room temperature ferromagnetism. The CoTb-based materials are amorphous at normal deposition condition. The structural phase transformation from amorphous to crystalline takes place at elevated temperatures above 400℃. On the other hand, FePt-based thin films crystallize in close pack FCC structure that tend to show (111) texture. On deposition at elevated substrate temperatures or post annealing at elevated temperatures above 400℃, the FCC structure transforms to $L1_0$ ordered FCT structure. Both these materials in thin film form exhibit perpendicular magnetic anisotropy whose strength is sensitive to the several factors such as film composition, film thickness, deposition condition, insertion of underlayer/overlayer, third element doping, etc. These two class of materials offer a tunable magnetic magnetic properties due to which they become potential candidate for application in practical devices, particularly in high density recording media. Prior to the start of work described in this thesis, no reports were found describing the magnetic properties of CoTbNi and FePtCo ternary alloy thin films except reports on binary alloy films such as CoTb, CoNi, FePt, CoFe, CoPt, etc. By studying the observed magnetic behaviour of these ternary alloys, a broader understanding of physics of these class of materials should be achieved, which will lead to the development of new knowledge to explain the phenomena observed.

In the current thesis work, thin films of CoTbNi and FePtCo were fabricated using DC magnetron sputtering system. The films were deposited by co-sputtering of Ni target with $Co_{85}Tb_{15}$ alloy target and Co target with $Fe_{40}Pt_{60}$ alloy target to achieve CoTbNi and FePtCo ternary alloy films respectively. CoTbNi films were prepared in two different conditions, one deposited at room temperature called as-deposited and the other annealed at 400℃ after deposited at room temperature called post-annealed. On the other hand, FePtCo films were prepared under three different conditions. First set of films were deposited at room temperature, second set of films were deposited at substrate temperature of 400℃, and the third set of films were deposited over the 2 nm thick Cu underlayer at room temperature. Film compositions were analyzed by EDX spectroscopy equipped with SEM. The film surface topography and surface roughness were studied in detail using two techniques, AFM and 3D optical profilometer. The detail investigations of crystal structure were performed using XRD as well as GIXRD. The magnetic properties were measured using VSM at room temperature and temperature dependent magnetic behaviour of CoTbNi films was also measured using VSM.

The elemental colour mapping of EDX spectra has established that the atoms are uniformly distributed and no concentration of particular atom in particular region of sample were observed in both CoTbNi and FePtCo films. This indicates the uniformity and homogeneity of the deposited films. The film surface roughness measurement on both films shows only a small variations for different compositions. The observed values of $S_a$ and $R_a$ are sufficiently smaller as compared to the overall film thickness of these films. Annealing of the films result reduction in film surface roughness due to the migration of atoms.

The XRD measurement of CoTbNi alloy films shows that both as-deposited and post-annealed films are amorphous. The results indicate that the crystal structure of CoTbNi films does not change with addition of Ni up to 81 at. %. Also the annealing temperature of 400℃ (673K) is not sufficient for structural phase transition from amorphous to crystalline. On the other hand, GIXRD measurement of FePtCo alloy films identified that these films crystallize in close pack FCC structure. The results indicate the formation of (111) texture under all deposition conditions. However, the annealing at 400℃ and insertion of Cu underlayer to FePtCo films enhance the formation of (200) texture along with (111) texture. In all three deposition conditions, the lattice constants of FePtCo films decrease with Co addition due to the smaller atomic radius of Co than Pt. A random variation of lattice parameters was observed in in-situ annealed films, particularly for 17 at. % Co doped FePt film resulting large XRD peak broadening. The insertion of Cu-underlayer also results reduction in lattice parameters as compared to the as-deposited and in-situ annealed films. This leads to a conclusion that the lattice parameters of these films are sensitive to deposition conditions along with the film composition. The calculation of average crystallite size also indicates that films prepared under different conditions give different crystallite size. Though particular pattern of variation of average crystallite is not observed with Co addition under all deposition conditions, the results showed an overall decrease with increase in Co addition.

The room temperature M-H measurement shows that CoTbNi alloy films exhibit room temperature ferromagnetism. The coercivity of both as-deposited as well as annealed films varies with Ni addition and higher Ni content films have larger perpendicular coercivity. The Ni addition in as-deposited films results reduction in saturation magnetization, remanent magnetization, and squarness of M-H hysteresis loop. However, annealing enhances the saturation magnetization and perpendicular remanence up to 72 at. % Ni addition and also perpendicular squearness. Further increase in Ni content results reduction in magnetization of annealed films. One of the most important results observed for CoTbNi films is that the perpendicular magnetic anisotropy for as-deposited films in higher Ni content CoTbNi films. The anisotropy strength i.e., effective anisotropy constant falls linearly with increase in Ni content of the films. Moreover, perpendicular magnetic anisotropy is lost by annealing of the films. This observation is closely attributed to bond orientational anisotropy which generally occur in amorphous materials due to stress developed during the deposition of the films. Upon annealing of the films, stress induced is relieved due to migration of atoms and lose magnetic anisotropic. The M-T measurements under FC and ZFC condition indicate a complex magnetization process. The ZFC curves show an unusual behaviour and magnetization under ZFC shows gradual increase up to room temperature. The large difference observed between magnetization measured under FC and ZFC condition is due to the non-collinear magnetic ordering such as sperimagnetism, which usually arises in amorphous CoTb films.

The room temperature M-H measurement of all FePtCo films prepared under three deposition conditions also show room temperature ferromagnetism. The Co content of the films as well as the film deposition conditions are found to play significant role on magnetic properties of these films. The in-plane coercive field of as-deposited films increases with Co content of the films but perpendicular coercive field decreases. On the other hand, the annealed and Cu-underlayered films are found to possess nearly same in-plane coercive field and show similar nature of variation with film composition. Moreover, these coercive fields are found to be greater than coercive field of as-deposited films except for 30 at. % Co doped film for which coercivity is nearly same under all deposition condition. The coercivity of annealed and Cu-underlayered films vary randomly in perpendicular direction. An overall increase in magnetic hardness of annealed and Cu-underlayered films are thus observed over as-deposited films. One of the striking result observed for these thin films is the variation of saturation magnetization as a function of Co content and deposition conditions. Under all deposition conditions, saturation magnetization decreases with increase in Co doping which is attributed to the antiferromagnetic interaction between Co sublattice and FePt sublattice with unequal magnetic moment. This antiferromagnetic interaction takes its peak strength at 17 at. % Co for annealed and Cu-underlayered film which is evidenced by the sharp reduction in saturation magnetization. Thus above 17 at. % Co doping for annealed and Cu-underlayered films, saturation magnetization again increases. On top of this, Cu-underlayered films possess larger saturation magnetization. A similar observation is also found for variation of remanent magnetization and an overall decrease in remanent magnetization is seen with increase in Co content for all films prepared under three conditions. The squareness of M-H hysteresis loop of all films also decreases with increase in Co content of all films. The Cu-underlayered films possess largest remanent magnetization and have better squareness M-H loops. All prepared thin films under three deposition conditions exhibit in-plane magnetic anisotropy with large effective anisotropic constant. The nature of variation of anisotropy constant as a function Co content for all films is similar to the nature of variation of saturation magnetization which decreases with increase in Co addition. The decrease in anisotropy constant is attributed to the antiferromagnetic interaction. The Cu-underlayered films are found to possess largest effective anisotropy energy over other films with same composition prepared under as-deposited and annealed conditions. This result shows that insertion of 2 nm Cu-underlayer plays a significant role in enhancing the coercivity, saturation magnetization and anisotropy energy of FePtCo ternary alloy thin films. Thus choosing a suitable thickness of Cu-underlayer may help tuning to achieved desired magnetic properties of these alloy thin films.

## Future Scope

In order to gain further understanding of the magnetic behaviour of CoTbNi films, M-H measurements at various temperatures and corresponding M-T measurements need to be carried out. The annealing of these films at elevated temperatures above 400℃ is expected to crystallize this class of materials whose magnetism is yet to be understood. The magnetic behaviour of this class of materials in ultra-thin thin film form and insertion of various magnetic/nonmagnetic underlayer/overlayer have been studied in limited reports. All the above mentioned studies is believed to provide new understanding of magnetic behaviour in these class of materials.

The study in this thesis was carried out only on the chemically disordered FCC phase of FePtCo alloy films of the same thickness and magnetic behaviour is well established in this thesis. However, the magnetic behaviour of varying thickness is still to be established. Also, the insertion of magnetic/non-magnetic underlayer of varying thickness is expected to enhance the magnetic properties of this material. In order to further understand how this material behave when FCC phase is transformed to $L1_0$ FCT phase, a detail investigation is now needed. Further research is needed to tune this material to achieve perpendicular magnetic anisotropy with an easy axis along c-axis along with reduction in structural ordering temperature. These above mentioned studies if performed will add more knowledge to understanding of the magnetic behaviour of this material.