Chapter 8

Conclusion and Future Scope

8.1 Conclusion

This thesis presents the synthesis of YIG and TmIG thin films using sol-gel-based spin-coating, which differs from the literature-reported sophisticated methods like PLD, LPE, and rf sputtering. This method, with further accessibility, such as a clean room and controlled atmosphere, can be an alternative to these expensive methods with low-cost deposition ability. The sol-gel-based spin coating has synthesized both the polycrystalline and epitaxial thin films. The polycrystalline thin films show a high crystallinity phase with high saturation magnetization and bulk nanoparticle-like qualities. The epitaxial thin films have high anisotropy due to the strain in the thin films. Substrate defects give rise to some spikes in the epitaxial thin film that need to be reduced by etching to get better results. Below is the conclusion of the experimental outcome of each chapter:

In **chapter 4**, the thesis presents an optimization of the polycrystalline YIG thin films deposition conditions, and the synthesis annealing duration reported was 2 hrs, 5 hrs, and 10 hrs. YIG thin films annealed for 2 hrs did not had high crystallinity, and saturation magnetization of the YIG 10 hrs has been reduced due to the higher annealing duration, which has created oxygen vacancy. The structural, elemental, and magnetic study confirms that the YIG 5 hrs sample has the highest saturation magnetization of 3.13 $\pm$ 0.03 μ_B/f.u. and was studied further for the magnetic dynamics study after confirming the stoichiometry and ionic environment was maintained using the XPS. The magnetic study confirms the effective magnetization of 0.1887 T and α is 4.7 $\pm$ 0.4 $\times 10^{-3}$ with the linewidth because of inhomogeneous contribution is 5.0 $\pm$ 0.4 mT. The α value is lower than 2.7 $\times$ 10^{-2} to 1.2 $\times$ 10^{-1} of the previously solution-based method, and the higher inhomogeneous contribution has a source in the grain boundaries and the defects [134].

In **chapter 5**, epitaxial (18 $\pm$ 1 nm) YIG thin film on the GGG (111) single crystal has been grown, and its magnetic properties are discussed. Strain calculation is done using the synchrotron GIXRD. Considering the magnetostriction constant ($\lambda_{(111)}$ = -1.7$\times 10^{-6}$) from the literature, the stress-induced magnetic anisotropy has been estimated to be K_σ = 4.4 $\pm$ 0.002 kN/m^2. The total anisotropy estimated by the FMR has been K = 4.69 kN/m^2. This chapter confirms that the significant contribution to total anisotropy is stress-induced magnetic anisotropy, and the reported anisotropy is positive in contrast to the PLD-grown similar annealing condition sample -4.9 kN/m^2 anisotropy.

In **chapter 6**, a polycrystalline TmIG thin film of thickness 22 $\pm$ 1 nm thickness has been grown on the thermally oxidized Si(100). XPS presented for the TmIG showing the stoichiometry is maintained in the grown sample. The experimental magnetic study confirms that the low compensation temperature of TmIG thin film is $\approx$15 K, which aligns with the available literature predicting the value of 14 K [23]. In addition, the low-temperature modulated ferromagnetic, where two competing lattices overlap and give kink-type magnetic hysteresis at 5 K, along with the room-temperature ferrimagnetic state, have been observed with the SQUID-VSM.

In **chapter 7**, high crystalline epitaxial TmIG of thickness 12 $\pm$ 1 nm has been grown on the GGG(111) single crystal using the sol-gel-based spin coating. The epitaxy of the thin film is confirmed with the synchrotron GIXRD. The high SOC in the TmIG causes a decrease in the g-factor. The high total anisotropy is the reason for the PMA in the thin film, and polar-MOKE confirms it. The significant contribution of total anisotropy is stress-induced anisotropy. The damping parameter estimated with the FMR is 0.018 $\pm$ 0.004, similar to the higher α PLD-grown samples [64]. The total anisotropy is 20.0 kN/m^2, which is much higher than the previous work, and this is an advantage of this method for the spintronics where moderate anisotropy is needed to stabilize the domain textures.

To conclude, sol-gel-based spin coating is a method to deposit high-strain epitaxial thin films. Better quality thin films with compressive positive magnetic anisotropy coefficient can be deposited in clean room facilities and controlled oxygen environments.

8.2 Future Scope

Further, to improve the quality of the thin film, synthesis is to be performed in a clean room and a controlled environment to enhance the surface quality and lower defects. The inverse spin Hall effect measurements must be conducted to measure the spin Hall angle in the YIG thin films to build a conduit with the lithography and study the magnonic propagation length and group velocity.

Higher-order spin wave excitation is observed in the epitaxial YIG, so studying and confirming its origin is also important for theoretical understanding. High effective magnetization calculated by FMR can be further explored with the stress-induced anisotropy on the dispersion curve, which is needed to understand and simulate the experimental results.

The question in the thesis for the nonlinear FMR linewidth in chapter 7 can be explored further with higher power FMR (vector network analyzer) and remeasure it. The epitaxial TmIG shows the spin-orbit torque (SOT). Further experiments will be performed on SOT measurement to observe the application potential. Because of the presence of the PMA, the potential for device fabrication can be explored. The magnonics devices with the heavy metal interface are excellent for memory and logic gate fabrication.