Preface

Since the proposal of Datta-Das transistor, area of spin injection and detection is in the spotlight for the last decade. Intense research in this field has successfully tackled many issues like conductivity mismatch. Use of tunnel barrier has improved the quality of the signal. Room temperature spin signals measured using all electrical non-local geometry of measurement in materials has made it more popular. Many such demonstrations of spin injection using metallic ferromagnets like Fe, Co and CoFe into Si, GaAs and Ge promises that this technique indeed a powerful tool for many future applications.

In our study, we have used an oxide magnetic material Fe_3O_4 as the spin injector which has the advantage of half-metallicity for the improved electrical spin injection and detection instead of conventional materials like Fe, Co etc. 3-terminal non-local geometry of electrical measurement is adopted for electrical spin injection throughout the course of study. Spin injection and detection is successfully extended to many systems like GaAs and Si with different doping concentration in an effort to obtain a combination of right material with high spin injection efficiency. Many such systems are compared and indeed the half-metallic Fe_3O_4 based devices perform better than the systems with conventional materials.

Chapter 1: In this chapter a brief introduction of the area of research is provided along with a summary of earlier studies in the field. From a brief discussion on the existing theory of spin injection and diffusion in various types of materials, we can see that the proper choice of material for any such studies is important. Interface between many systems such as ferromagnet/non-magnet, ferromagnet/insulator/non-magnet are compared and analyzed using existing theories with spin-polarization as a measure. Later on the discussion is extended specifically into semiconductors as our main goal is to study the spin injection and detection into semiconducting materials. A brief discussion on the criteria and importance of the materials chosen for our study is also presented.

Chapter 2: This chapter provides a brief introduction to half-metallic Fe_3O_4 and its crystal structure from the magnetism point of view. An introduction to the experimental techniques used during the course of the study is also provided at the second half of the chapter.

Chapter 3: Optimization of Fe_3O_4 thin film growth on different substrates is mainly discussed in this chapter. Based on the choice of substrates, growth of Fe_3O_4 can be tuned from a single crystal to polycrystalline thin film. In the presence of MgO insertion layer, Fe_3O_4 growth is found to be always (100) oriented single crystalline on GaAs, whereas only (111) oriented growth of Fe_3O_4 is present in the absence of MgO. Similarly growth and the subsequent basic structural and magnetization characterization are presented for Fe_3O_4 on Si and MgO/Si. Interestingly, magnetization measurements on Fe_3O_4 on different substrates show an exchange bias (EB) in a single magnetic film at temperatures less than 200 K. Several temperatures dependent hysteresis together with the training effect of the samples show that the observed EB has a similar exchange pinning behavior found at the ferromagnet-antiferromagnet bi-layers. Nature of EB is found to be highly directional and the magnitude of the coupling varies at different directions with respect to the crystallographic axis of Fe_3O_4 grown on various substrates. A possible reason for the observation of EB in a single magnetic layer is proposed based on the formation defects at regular sites in the thin film lattice. These defects are formed during the high energy PLD growth process which alters the regular local magnetic interactions of the lattice sites. If this interaction strength is high enough to influence the total magnetization of the material, then EB can set into this system together with the low temperature magnetic anisotropy variation.

Chapter 4: This chapter furnishes the details of the optimization of the tunnel junctions for the 3-terminal non-local geometry of electrical Hanle measurement on Fe_3O_4/MgO/GaAs. Successful observations of room temperature electrical spin injection and detection are demonstrated on different devices with varying injection current. Hanle measurements at different low temperature show a systematic variation of spin relaxation in n-type of GaAs. Similar room temperature studies are extended to p-type GaAs, where the observation of spin signal is otherwise difficult at room temperatures. Variation of MgO barrier thickness is shown to be having no effect on the observed spin signal, which in turn avoids the ambiguity of any spurious unwanted effects from the junction region.

Chapter 5: Observation of electrical spin injection and detection in various systems are discussed in this chapter. Similar to GaAs, Hanle measurements in Fe_3O_4/MgO/n-type Si as well as p-type Si is carried out with the drop of spin accumulation by at least 2 orders of magnitude. The presence and the absence of MgO in Fe_3O_4/MgO/n-type GaAs have an impact on the magnitude of spin accumulation. Interestingly we have observed a huge enhancement of spin accumulation at T ~120K in all devices with Fe_3O_4 as a spin injector irrespective of the substrates. Hence the Verwey transition of Fe_3O_4 has an enormous influence on the spin accumulation at any substrate. Origin of the huge enhancement of the accumulation is consistent with the temperature dependence of spin-polarization of Fe_3O_4. From our study, we have found out that all these Fe_3O_4 based devices on GaAs found to be superior to the usual Fe/MgO/GaAs devices.

Chapter 6: This chapter gives a broad summary of all the studies carried out during the tenure of work. It also discusses the importance and the impact of the work in the field of semiconductor spintronics devices. Future of the extension of this work looks very promising as these devices can be directly used for the realization of spin-transistors.