ABSTRACT

Spintronics is a multidisciplinary field whose central idea is to manipulate spin degrees of freedom in nano-devices. Many theoretical and experimental researches have nurtured the development of novel devices, hence high density data storage systems, spin logic circuits, magnetic sensors and many new devices in communication systems have mushroomed. In this scenario, Magnetic Tunnel Junction (MTJ) is a potential candidate to explore, since it is an essential component in read/write heads, magnetic storage and also in microwave oscillators. This thesis is based on the investigations carried out in two different MTJ structures.

Magnetization dynamics in two different multilayer systems is investigated analytically and numerically by solving the associated Landau-Lifshitz-Gilbert- Slonczewski (LLGS) equation. Dual barrier-Magnetic Tunnel Junction (MTJ) and Composite free layer-Magnetic Tunnel Junction have been modeled as an extended LLGS equation and investigated. Dynamics of the magnetization is studied by plotting the trajectories of the spin components of the free layer.

Initially Dual barrier-(MTJ) is modeled by its associated LLGS equation which includes inter/intra layer magnetic interactions. The dynamical equation is transformed stereographically on to a complex plane and it evolves as Cubic Quintic Nonlinear Schrodinger (CQNLS) equation. Using Hirota's technique, CQNLS equation is bilinearised and the excitations are found to be soliton solutions. Solitons emerge from this inhomogeneous nonlinear system representing a balance between the effect of dispersion and nonlinearity. Presence of these solitons as magnetic excitations in a ferromagnetic multilayer systems may help to understand the process of noise free non-volatile data storage and also in quantum computations.

The magnetic spin excitations as travelling waves are studied in detail in the CQNLS and this gives an interesting possibility of MTJ as STO. The components of magnetization show stable precession with respect to time, hence the device could act as Spin Torque Oscillator (STO). Fourier transform of those oscillating components is taken to find the frequency and Power Spectral Density (PSD). The frequency of the oscillator seems to increase when anisotropy is added to the free layer. Study of dispersion of the spin wave tells that the frequency of in-plane and out of plane precessional modes of the spin depends on current and wave vector. An interesting outcome of the study is that STO can be driven into its chaotic regime just by changing current and spin wave vector suitably. Application of an external alternating current locks the phase which increase the output power and reduce the distortions.

Next, ferromagnetic multilayer structure studied is a composite free layer-MTJ. This is modeled by its associated LLGS equation and it is modified into an NLS equation by stereographically projecting the spin on to a complex plane. The dynamics is studied by plotting the trajectories of the components of magnetization vector. A fourth order Runge-Kutta numerical integration on LLGS equation also confirms the similar trajectories of the spin components. This study establishes the possibility of a Spin Torque Oscillator in a composite free layer spin valve, where the exchange coupling is ferromagnetic in nature. In-plane and out-of-plane precessional modes of magnetization oscillations were found in zero applied magnetic field and the frequencies of the oscillations were calculated from Fast Fourier Transform of the components of magnetization and also confirmed from the analysis of period of oscillations. Power spectral density was also studied with the increase in current density. Maximum frequency of 39.9 GHz is reported for minimum current density of 1.1×10^6 A/cm^2. Finally the analysis shows highest frequency of 149 GHz ever reported, which is in the second harmonics for the specific choice of system parameters.

Very recently skyrmions were discovered and the characteristics are being studied worldwide. Hence the possibility of the structure to host skyrmions which could be used as information carriers in magnetic sensors and spin logic devices with very low current density is explored. So the dynamics of magnetic skyrmions is investigated in a composite free layer spin valve nano pillar. The composite free layer-MTJ having different coupling mechanisms in the absence of Dzyaloshinski-Moriya Interaction (DMI) is also investigated. The physical system is modeled by LLGS equation by incorporating all the terms responsible for effective magnetic field. Components of the spin vector are arrived analytically and plotted to study the dynamics and to trap skyrmions. Interestingly nano meter sized skyrmions and anti skyrmions are trapped with different helices in the free layer. The spin polarized current under specific choice of system parameters changes the droplet solitons into skyrmions and anti skyrmions. The current driven dynamics is studied and the condition at which an isolated skyrmion exists is reported. We have optimized the current density (J) and spin wave vector (k) for which Skyrmion Hall Effect (SHE) completely vanishes and as a result the velocity, size and shape of skyrmions are preserved. When the coupling between the composite free layers is changed, skyrmion-anti skyrmion pair and radial-chiral skyrmion pair emerge. For the specific values of (J) and (k) these pairs show coupled motion along the layer and hence these pairs could also be used as a bit in the data processing and storage devices. Our investigation ascertains that a single material can host all the magnetic structures if the current density, spin wave vector and coupling constant are suitably tuned. This study would really be of fundamental importance owing to the possible applications in information processing and data storage in skyrmion based logic circuits and magnetic sensors.

In the first chapter of the thesis, introduction to low dimensional ferromagnetic systems and interaction energies are discussed. In chapter 2, multilayer magnetic systems and new effects which change the magnetization

dynamics and hence leading to new advancements in technology is explained. The analytical and numerical methods to explore the dynamics is also elaborated. In chapter 3, investigation on the magnetization dynamics of Dual barrier-Magnetic Tunnel Junction is explained. The system is said to act as a memory device, where data is stored in the form of solitons. And the system is driven to its oscillating mode as STO which can also be driven to chaotic region. Phase locking the oscillator with external a.c and its merits is explained. In chapter 4, studies on the dynamics of composite free layer spin valve pillar is explained. Here the system is realised to act as STO with very high frequency. Next, the investigation is on the favourable condition of the system to host skyrmions without DMI is discussed. In chapter 5, summary of the work and conclusion is given.