Abstract

Spin Hall effect (SHE), first predicted by Dyakonov and Perel for semiconductors in the year 1971, and later remodeled by Hirsch in 1999 for the heavy metal system with large spin-orbit coupling has shown the possibility for next-generation memory recording media and nano-oscillators. The discovery of SHE opened a new field of research known as "Spin-orbitronics." In the last decade, researchers have extensively studied the SHE and associated spin-orbit torques (SOTs) in heavy metals (HM) with sizable spin Hall angle such as Pt, $\beta-$Ta, $\beta-$W, etc. to generate high-frequency signals in the GHz range and current-induced magnetization switching. However, efficient control of magnetization still requires significant advancement in this field. This thesis deals with some of the developments such as interface modification, crystalline phase engineering, exploring exchange biased systems and 2D materials for better understanding and control of current-induced SOTs. For these developments, we have studied three different ferromagnet/non-magnet (FM/NM) heterostructures.

First, the conventional HMs are chosen as a non-magnet in FM/NM system for the study of their detailed magnetization behavior. The Co/Pt bilayer is one of the most widely studied FM/HM systems. We have observed an enhanced Gilbert damping and spin mixing conductance due to post-growth annealing. These results can be correlated with higher spin memory loss at the inter-diffused interface in Co/Pt system. This study provides insight into spin pumping in FM/HM heterostructures and suggests a crucial role of interface modification. We have systematically studied the effect of the phase purity of the Ta thin films on the spin pumping, SHE and SOTs. Using FMR and inverse spin Hall effect (ISHE) measurements, it is observed that the crystalline phase-dependent Ta thin films generate a large spin current from the low resistive mixed-phase Ta. A detailed study of spin-orbit torque is performed using zero-bias and DC-tuned spin-torque ferromagnetic resonance (STFMR) measurements. These results show dominant damping-like torque in low resistive mixed-phase Ta and a dominant field-like torque in pure $\beta-$phase Ta pointing to SHE and Rasbha mechanism of SOT, respectively.

Secondly, the magnetization dynamics in the metallic antiferromagnet (AFM) interfaced with ferromagnet is studied. The heavy metal-based AFM system (*e.g.,* IrMn, PtMn) not only provides a large exchange bias field but also works as an efficient spin current source. The spin pumping and SOTs in NiFe/IrMn system are studied using FMR and STFMR measurements.

The magneto-dynamic measurements suggest that the exchange bias produces a unidirectionality in Gilbert damping. The SOT studied using angle-resolved STFMR measurements in polycrystalline IrMn thin films suggests the generation of unconventional SOTs in this system, which is forbidden in the FM/HM system. These unconventional SOTs which are present only in exchange biased sample, originates from spin current with spin polarization along the direction of charge current and perpendicular to the FM/AFM interface.

In the last part of the thesis, the 2D materials for the presence of SOTs and interfacial Dzyaloshinskii-Moriya interaction (iDMI) are investigated. It is found that the monolayer Graphene (Gr) due to the Rashba spin-orbit coupling generates unconventional SOTs, specifically a large out-of-plane damping-like torque, that can be useful for switching in perpendicularly magnetized systems. On the other hand, using direct detection of iDMI with Brillouin light scattering experiments, a large defect induced iDMI in few-layer MoS_2/NiFe heterostructures is observed.

In summary, the spin current-induced phenomena and SOTs in various FM/NM heterostructures are studied in detail. It is found that the interface modification in FM/HM and the crystalline phase of HM play essential roles in the generation and transfer of spin current. The generation of unconventional SOTs in exchange biased systems (NiFe/IrMn) and low dimensional materials (Gr) provide future scope for further study and device designing. The observation of a large iDMI in few-layer MoS_2/NiFe will be useful for obtaining chiral spin textures.