Abstract

The backbone of many present and future technologies such as magnetic data storage, magnetic logic and sensors relies on developing and in-depth understanding of new class of patterned arrays of nanomagnets. In the last few decades, it has been proposed that novel magnetic structures with precisely controlled dimensions and shapes at the nanoscale namely magnonic crystals (MCs) have potential applications in spin logic, spintronics and other spin-based communication devices, where spin waves (SWs) are carrier waves. Due to shorter wavelengths as compared to electromagnetic waves of the same frequency, spin-wave based devices offer the potential to aid the miniaturization of microwave communication. With the recent advancements in sophisticated lithography techniques, it has been possible to fabricate robust design which can function as attenuators, filters, phase-shifters, couplers, logic gates and transistors etc. There are many challenges that need to be addressed before the full potential of MC based devices is realized, such as fabrication of bi-structure (combining two structures in one MC) or tri-structure MCs on magnetic thin films.

The main objectives of the thesis are to elucidate the spin dynamics in different magnonic systems including multilayered thin films and patterned magnetic nano-structures. The samples are prepared by various techniques including ultra high vacuum magnetron sputtering, electron beam evaporation and focused ion beam lithography. The initial characterizations of the samples are done by the X-ray diffraction (XRD), scanning electron microscopy (SEM), energy dispersive X-ray (EDX), atomic force microscope (AFM) and X-ray Photoelectron Spectroscopy (XPS).Custom built time-resolved magneto optical Kerr effect set up in collinear pump probe geometry has been employed for the measurement of spin-wave dynamics. The experimental results are analyzed and interpreted with the aid of finite difference and finite element method based micromagnetic simulations (OOMMF) and macrospin modeling of Landau-Lifshitz-Gilbert (LLG) equation. The topic of modification of magnetic properties was explored in two main categories of systems: i) patterned magnetic structures: The effects of geometrical parameters and applied magnetic field orientations in a two-dimensional array of $Ni_{80}Fe_{20}$ annular antidot lattice, binary magnonic crystals and slotted nano-cross are investigated in reasonable details. For homogeneous annular antidot lattice geometry, interacting SW modes are observed due to interaction between dot and antidot with varying bias magnetic field strength. A flattened four-fold rotational symmetry, mode hopping and mode conversion leading to mode quenching for spin wave modes are observed in this lattice with the variation of the bias field orientations. Using numerical simulations, we showed the anisotropic spin wave propagation through the lattice which indicates their possible applications in spin wave filter and other nonlinear spin wave devices. A new design of binary MC, where nanodots of two different sizes were diagonally connected forming a unit cell, calling as binary MC has been introduced to further control the SW propagation in the MCs. Interestingly, at $\phi = 0°$, the spin-wave mode profiles show frequency selective spatial localization of spin-wave power within the array. With the variation of ϕ in the range $0° < \phi \leq 45°$, we observe band narrowing due to localized to extended spin-wave mode conversion. We observed that just by tuning the applied field angle, the confined SW modes are restored to extended SW modes due to strong dipole-exchange coupling in these newly developed binary MC. Also, tri-structure MC, where three different size and shape antidots are fabricated in a periodic manner calling as slotted nano-cross lattice. The SW modes were markedly modified due to the existence of modulated demangetizing field distributions at the edges of the antidots. Using micromagnetic simulation, spin wave dynamics of different shaped single nanodots and nanodots arrays with varying edge-to-edge separations have been studied. We observed splitting in the modes from single dot to dot array samples. The power profile confirms the nature of the observed SW modes which show quantized mode, centre mode and edge mode like nature. Vortex states are observed in an array for all the shapes at H_{bias} = 0 while at H_{bias} = 1.12 kOe we observe onion, flower and buckle states in different shaped dot elements. ii) magnetic layered structures: The magnetization dynamics in multilayers with Ta capping (Ta/Ni80Fe20/Ta) and without Ta capping layer (Ta/Ni80Fe20) with varying Py thickness are measured. Interestingly, the decay time of spin wave is found to be highly dependent on top layer of samples. The decay time increases with increasing Py thicknesses for Ta/Py/Ta samples implying that the enhancement of decay time is caused by the Ta/Py/Ta interfaces. Whereas, for Ta/Py samples decay time decreases with increasing Py thickness. The results of this work extend the knowledge on the magnetization dynamics of Py thin films giving informations on how to resume and even enhance the spin mobility after a deleterious oxidation process. This can open new scenarios on the building process and on the maintenance of fast magnetic switching devices. All the results obtained during the course of this thesis are important in terms of their potential applications in future data storage and nanoscale microwave communication systems.

Keywords: Magnonic crystals, Spin wave, Magnetic thin film, Micromagnetic simulation, Time-resolved magneto-optical Kerr effect microscopy