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**Thesis Title:** Investigation of GHz and THz Frequency Dynamics of Thin Films and Micro- and Nanostructures

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**Abstract:**

In the era of escalating demands for computational power, traditional electronic circuits are nearing their limits with respect to miniaturization, performance, and energy efficiency. Among others, spintronic and magnonic devices present a promising alternative by utilizing spin waves (SWs) instead of electric charges to carry information, potentially revolutionizing future spin-based technologies. This thesis explores the dynamic magnetization phenomena in various ferromagnetic nanostructures, emphasizing the control and reconfigurability of SW properties within magnonic crystals (MCs)—periodically structured metamaterials that exhibit unique magnetic characteristics, paving the way for the next generation of highly efficient and miniaturized microwave devices.

This thesis explores several innovative approaches to the control and application of SWs in ferromagnetic thin film heterostructures and nanostructures. Initially, the reconfigurable nature of SW dynamics in 1D MCs in the form of ferromagnetic nanostripe arrays was investigated through a combination of experiments and micromagnetic simulations. This study revealed the potential to manipulate SW propagation by varying nanostripe thickness and external magnetic field geometry, paving the way for reconfigurable magnonic circuit components. Such a remarkable variation of SW spectra may inspire the development of SW waveguides with wedge-shaped thickness profile which may accommodate different parallel frequency channels lying adjacent in the same waveguide structure without the need for additional nanopatterning.

The research focus then shifts from conventional magnonics to hybrid magnonics, utilizing ferromagnetic nanocross elements as magnonic cavities. The study demonstrated that those nanocross elements act as magnonic cavity and dipole-exchange interaction within the array results in the observed magnon-magnon coupling in the form of an anticrossing phenomenon. The strength of magnon-magnon coupling has been tuned by adjusting microwave excitation power and external magnetic field orientation. Further work focused on controlling the anticrossing phenomenon in nanocross structures by varying the nanocross dimensions and using the same broadband ferromagnetic resonance technique, achieving significant enhancements in coupling strengths. These results will have significant implications for on-chip magnonic devices for quantum information processing and communication.

Furthermore, the amplification of SWs in cobalt-based nanomagnet systems using alternating current spin-orbit torque (ac SOT) has been investigated. Employing time-

resolved magneto-optical Kerr effect (TR-MOKE) under bias field-free conditions, we have achieved resonance with intrinsic SW modes by applying radio frequency (rf) currents with different frequencies. The amplitude of these SWs increased up to ten-fold with varying rf power. Our findings highlight significant SW amplification and enhanced signal-to-noise ratios across various frequencies. This establishes ac SOT as a pivotal tool for tailoring SW dynamics in nanoscale devices, promising advancements in spintronic applications by enabling efficient information transmission and optimized SW characteristics.

The focus of the thesis then shifts to the investigation of spin pumping, spin-mixing conductance, interfacial spin transparency and spin diffusion in topological insulator (TI)/ferromagnet FM heterostructures using TR-MOKE techniques, revealing efficient spin current injection and high interfacial spin transparency. The role of topological surface states and high spin-orbit coupling of the TI on the spin pumping and the ensuing modulation of Gilbert damping have been extensively studied.

Finally, we investigated the THz polarization efficiency of metallic wire grid (MWG) structures and demonstrated the enhancement of polarization efficiency by reducing the pitch of the wire grid structures using THz time-domain spectroscopy. The achievement of high polarization efficiency over a relatively broadband THz frequency promotes their application potential in various THz applications including THz spintronics. These findings collectively advance the understanding and technological potential of THz spectroscopy.

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