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主　論　文　の　要　旨

論文題目 Microscopic theory of antiferromagnetic spin dynamics driven by magnetic field and electric current
（電流および磁場に駆動された反強磁性スピンダイナミクスの微視的理論）

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論　文　内　容　の　要　旨

Spin electronics, or spintronics for short, aims to utilize both the magnetic and electric properties of electrons to expand upon the conventional physics of electronics. So far, spintronics has proven itself useful through the discovery of the Nobel prize winning giant magneto resistance and magnetoresistive random access memories.

Such remarkable discoveries were made in ferromagnets, and research in other classes of materials such as antiferromagnets (AFs) remain relatively limited. AF is another class of magnetic material that has a number of advantages over ferromagnets, such as the robustness to magnetic perturbations, THz range spin dynamics, and absence of stray fields. Immunity to external magnetic fields and absence of stray fields is however a double-edged sword, and makes the manipulation and measurement of AFs a challenge compared to ferromagnets. In this thesis, we theoretically explore different ways to tame AFs to our advantage.

A domain wall is a topologically stable texture in magnetic materials that is expected to play an important role as information carriers in spintronic devices. Dynamics of domain walls is one of the most fundamental processes in magnetic materials, and is of interest from both theory and application perspectives. In the first part of my thesis, I explored the dynamics of AF domain walls driven by inhomogeneous magnetic fields. The Lagrangian and the equation of motion of AF spins under an inhomogeneous magnetic field are derived. The dynamics of AF domain walls is investigated using the method of collective coordinates. A solution is found that describes the actuation of a domain wall by an inhomogeneous field, in which the motion is initiated by a paramagnetic response of wall magnetization, which is then driven by a Stern-Gerlach like force. The validity of the theory is backed up by atomistic simulations.

In the second part of the thesis, we explored the effect of conduction electrons on AF spins. A microscopic calculation is presented for current-induced spin-transfer torques (STT) and damping torques in metallic AFs. It is found that the sign of STT is opposite to that in ferromagnets because of the AF transport character. Enhancement of the current-to-STT conversion factor near the AF gap edge is observed. The dissipative torque parameter and damping parameter arise from spin relaxation of electrons. Physical consequences are demonstrated for AF domain wall dynamics. Similarities to the ferromagnetic case are pointed out such as the intrinsic pinning and the specialty of $\alpha_n/\beta_n = 1$. Finally, I give a possible explanation for the experiment on domain wall motion in ferrimagnetic GdFeCo near its

angular-momentum compensation temperature.

Spin waves are collective excitations of magnetically ordered systems that carry energy and angular momentum. In the last part of the thesis, we investigate the effect of electric current on AF spin wave dispersions. We identify two different sources of spin-wave Doppler shift induced by electric current, while in ferromagnets there is only one. The two STTs that give rise Doppler shift have opposite signs and compete against each other; one dominates at the AF band bottom, and the other dominates near the AF gap edge. The effect of next nearest-neighbor hopping is investigated, where the crossover from ferromagnetic STT to antiferromagnetic STT can be observed by tuning the hopping parameters. In the limit of only the next-nearest neighbor hopping, the two STTs coincide to form the ferromagnetic STT.

To conclude, I have investigated the effects of magnetic field and electric current on AF spin dynamics. It is shown that AF domain walls can be driven by inhomogeneous magnetic fields, and an analytic solution for the domain wall dynamics is derived. Spin-transfer torques and damping torques on AF spins are also studied starting from a microscopic Hamiltonian. The differences between AF domain wall motion and ferromagnetic domain wall motion are demonstrated. The effect of current on AF spin waves is also discussed.