Professorship of Chip-Based Magnetic Sensor Technology
TUM School of Computation, Information and Technology
Technical University of Munich

Research Internship

# Micromagnetic Simulations of Magnetic Tunnel Junctions for Spin Wave Readout Applications

Student:
Supervisor: Felix Naunheimer, Markus Becherer

**Schedule:** Start: End:

**Topic Description:**
Magnetic memory is widely used in commercial technologies such as hard drives and Magnetoresistive Random Access Memory (MRAM). MRAM relies on structures called Magnetic Tunnel Junctions (MTJs), which consist of two ferromagnetic layers separated by an insulating barrier. These layers can have their magnetization aligned either parallel or antiparallel, depending on the influence of an external magnetic field. This alignment affects the electrical resistance of the junction, thereby encoding a memory state that can be electrically read out.
This process, however, is primarily governed by magnetostatic interactions. When considering dynamic phenomena such as spin waves—which are collective oscillations of magnetization used in spin wave computing—the task of reading out the magnetic state becomes significantly more complex.
Spin waves are typically excited using simple microstrip transducers operating in the gigahertz frequency range. The readout is usually performed by detecting a corresponding gigahertz signal induced in a loop-shaped antenna. However, this signal is extremely weak because spin waves carry very little energy, making their detection particularly challenging.[1] However, M. Endo et al. have demonstrated a MTJ sensor utilizing a vortex-type sensing layer, which enables the detection of small magnetic field variations.[2]
In this work, the student focuses primarily on understanding spin wave dynamics through micromagnetic simulations. A key objective is to reconstruct and implement the vortex-type MTJ within our in-house MuMax3 [3] simulation wrapper, enabling further investigation of its behavior and potential for spin wave-based applications.

**Workpackages**

1. Literature research on spin waves and magnetic tunnel junctions
2. Einarbeitung in die Simulationsumgebung (MuMax$^3$/Matlab)
3. Implementation of required geometries and materials
4. Simulation of the developed structure

**Literature**

[1] Design of on-chip readout circuitry for spin-wave devices
[2] Control of sensitivity in vortex-type magnetic tunnel junction magnetometer sensors by the pinned layer geometry
[3] The design and verification of Mumax3
[4] Introduction to spin wave computing