

The goal of the project is to investigate spin-torque nanooscillator (STO) dynamics under any given magnetic field. STO is a modern nanoelectronic device, where the central part is constituted by a very thin (few nanometers thick) magnetic layer. The electric current flowing through this layer may be polarized in terms of spin, which means that the majority of the electron spins is aligned with some single direction. If this is the case and if the current is strong enough, its flow will create stable oscillations of the magnetic moments in the thin nanolayer, which will behave in a manner similar to the well-known spinning top toy. As a result, we obtain a functional STO device, which can be used e.g. in electronic circuits as a high-frequency signal generator, leading to innovative devices and development of future nanotechnology.

Another interesting feature of a STO is its ability to detect rapid magnetic field changes. Depending on the material and other technological parameters of the device, its oscillations frequency may vary greatly for different directions and strengths of the external magnetic field. In consequence, it is possible to construct an extremely small and yet very precise magnetic field sensor based on the STO technology. By monitoring the changes of oscillation frequency, one is able to reproduce the changes of external magnetic field, which may be useful e.g. for reading data from a magnetic hard disk drive (HDD), which is an important part of most computers nowadays.

During past few years, the introduction of solid state drives (SSD) technology has created new standards for read and write speeds which HDDs are unlikely to successfully compete with in the foreseeable future. Nonetheless, as the average cost of one byte storage is significantly lower in the case of HDDs when compared to SSDs, they remain a vital part of information technology industry. Additionally, one should note the great interest attracted by recent advances in solutions regarding hybrid drives, which are designed to combine advantages of both HDDs and SSDs by using the SSD part of the drive to act as a temporary memory for the data stored on the more cost-efficient HDD part. Therefore, further investigations on both writing and reading HDD techniques and innovative devices, such as this project, are crucial for information storage development.

Another branch of electronics which will possibly benefit from the results of this project is identification of defects during electronic circuits production process, especially in the context of extremely dense integrated circuits, where fast and precise magnetic field nanosensors may be used to examine electric current distribution. For this application, it is especially important that the sensor is able to work with inhomogeneous external fields, which is a major topic in this project.

The project will create software and theoretical framework for STO simulations in the presence of arbitrarily defined magnetic field using a so-called micromagnetic approach, which unlike more traditional approaches is able to model inhomogeneities of a system and an external field – feature crucial from the point of view of STO dynamics and magnetic field detection, especially for fields coming from very small magnetic domains on extremely dense modern hard disks. The created software will be open-source and fully compatible with Object-Oriented Micromagnetic Framework, which is an already existing popular environment for simulations.

Another important part of the project will be investigation of STO material, geometrical and technological parameters in order to find the most suitable system for the magnetic field detection. We will be especially concerned with sensitiveness of the oscillations to the changes of external magnetic field and ability to produce a clear signal without much disruption from thermal noises. Additionally, the project will analyze the influence which additional technological devices, such as e.g. magnetic shields that screen the field coming from neighboring hard disk domains, have on STO readout device efficiency. We will try to maximize the speed of the magnetic field detection, which will be useful for construction of extremely fast computers in the future. Finally, we will analyze an important factor which is the effect of temperature and thermal noise on the magnetic field detection process.

Numerical calculations will be performed using Prometheus supercomputer located at Academic Computer Centre Cyfronet AGH University of Science and Technology (UST), which is currently the most powerful supercomputer in Poland and one of the top 30 supercomputers in the world and top 12 in Europe in terms of computational power. It consists of over 40 000 Intel Haswell cores and provides approximately 216 terabytes of DDR4 RAM as well as a total file system capacity of 10 petabytes, with access speed up to 180 GB/s. Due to the usage of the latest direct water cooling technology, it also offers enormous savings in energy usage when compared to more traditional supercomputer architectures, which allows for increased performance at a lower price and with smaller environmental impact. Thanks to the opportunities offered by the Prometheus infrastructure, we will be able to massively increase the speed of our computations by using multiple cores for each single simulation.

Experimental examinations of thermal noise will be performed at AGH UST Department of Electronics, Magnetic Multilayers and Spin Electronics Group by researchers specialized in the magnetic sensors and noise problematics. We will use highly specialized electronic components allowing for fast and precise data acquisition. Samples will be prepared in collaboration with Singulus Technologies AG in Germany and nanofabricated in the AGH Academic Center of Materials and Nanotechnology using advanced lithography system and an extremely clean, ISO 5 class room. Data collected in this way will be used to calibrate the model of thermal noise. In order to efficiently examine different models, we will use specialized artificial intelligence methods such as neural networks or hierarchical genetic algorithms.