The aim of the project is to design novel structures and theoretically investigate physical mechanisms particularly interesting from power consumption point of view, crucial for the concepts of green information technology. To achieve this aim, the authors will exploit advantages of spintronics which is a branch of nanoscience focused on research on physical systems where not only a charge of an electric carrier, but also its internal magnetic moment called spin is used. Therefore, in the project we will investigate structures consisting of ferromagnetic layers one hundred times smaller than the smallest object visible with an optical microscope.

The objective of the project is to investigate electric-field-driven dynamics of magnetoresistance in magnetic tunnel junctions (MTJs) that could work as non-volatile memory cells as well as microwave-frequency nanodetectors utilizing spin-dependent alternating current signal to direct current signal conversion called spin-diode effect. One of the most interesting parameter of ferromagnetic nanolayer is the direction of magnetization alignment in the absence of external magnetic fields called anisotropy axis. Electric-field-induced magnetic anisotropy change is of particular importance from the energy point of view as in this case the energy needed for the excitation is not lost as a parasitic heat dissipation in highly resistive voltage-controlled devices. In particular, voltage-induced ferromagnetic resonance in MTJ is one of the most promising phenomena for future microwave detectors design. By applying an alternating voltage to a high-resistance MTJ, one can observe perpendicular magnetic anisotropy changes which may result in magnetization precession as the equilibrium state changes with voltage. At the same time, the effects of small current flow (current intensity is adjustable with the junction development technology) on magnetization remain negligible. The signal can be detected by measurements of the static voltage arising from the mixing of alternating current and resistance changes during magnetization precession.

Taking advantage of international collaboration, we will deposit samples using magnetron sputtering and molecular beam epitaxy, which will allow us for investigations of variety of MTJs parameters, particularly anisotropies differing in terms of both amplitudes and directions. Material parameters will be optimized in order to obtain the highest output signal and narrow ferromagnetic resonance line. Samples will be nanofabricated by means of three-steps electron beam lithography into variety of shapes and sizes scaling down to 100 nm with usage of technology available at the AGH Academic Center of Materials and Nanotechnology. Measurements of spin-diode effect will be conducted in SPIN-LAB laboratory in Department of Electronic on AGH, equipped with highly-specialized apparatus allowing for microwave frequency measurements in temperature regime between 14 K and 475 K and variety of external magnetic field.

The pioneering part of the project will be in particularly the investigations of the electric-field-driven spin-diode effect in the case of in-plane anisotropy, which has not been reported in any scientific literature yet, and research on emerging possibilities of electric-field-control of interlayer exchange coupling. Research on new phenomenon of interlayer exchange coupling changes due to applied alternating electric field can result in a new branch of devices and, in the future, give a possibility of performing experiments and development of such devices.
In order to both enhance experimental data analysis and perform modelling of new phenomena, micromagnetic simulations will be used. In this approach, ferromagnetic material is modelled as continuous medium with local magnetization vectors orientations described with differential equations. In order to run numerical calculations, space is discretized into mesh of rectangular cells with the assumption that each one can be described with a single magnetization vector. Then, interactions between each cell and possible external conditions, such as electric field affecting anisotropy, is taken into account.

All calculations will be performed using PL-Grid infrastructure on Prometheus super computer, which is the newest and the most powerful supercomputer in Poland, with computing power of over 40 000 personal computers. We will exploit the possibilities given by the PL-Grid infrastructure and perform fully-parallel calculations. We will utilize our previously designed software, particularly models of magnetoresistance and tools for spatially-resolved spectrum calculations, as well as develop new solutions for further, advanced analysis including wavelet transform. All theoretical investigations will be kept as close to planned experiments and upcoming literature as possible.

The experimental results, software tools and calculation methods obtained during the project will allow for efficient modeling of spintronics nanodevices and greatly enhance the possibilities of understanding complex results as well as designing structures and optimizing parameters for particular devices before fabrication. Thus, the project will result in time and cost reduction of the sample preparation for further investigations in spintronics.

The final outcome of the research project will be designs of devices combining non?volatility characteristic for the magnetic elements with low power consumption and heat dissipation associated with the electric?field-control, which will lead to towards cheaper and more efficient future nanoelectronics.