Spin electronics is the field of science, which aims to use not only the electron charge, but also its spin for storing and processing the digital information. Spin (often understood as the angular momentum of an electron) is associated with magnetism – the ordered spin orientation is revealed by the existence of a magnetic field.

The project aims to investigate physical and magnetic properties of thin (of the order of 1 nm, that is several monoatomic layers) magnetic layer adjacent to heavy metals (such as tungsten, iridium, tantalum, platinum, etc.). The properties of very thin layers are often different and surprising compared to the ones known form a macro-scale. In particular, in case of thin magnetic layers one can change (and control) the so-called magnetic anisotropy, which is the preferred direction of magnetization using a spin-polarized current, or electric field. In addition, using the thin metal layers and passing the charge current along such a layer, in some materials one can observe spin currents (i.e., the flow of electron spin contrary to electron charge) generated in a direction perpendicular to the layer (and the charge current). This creates a unique possibilities of controlling the magnetism the magnetic system deposited on non-magnetic conductors, which can be used for information recording and storage.

The conditions, where relatively large spin current are produced in such systems are expected for the materials with a large spin-orbital interaction. In the simplest sense, this coupling, which is characteristic for a given element, is a measure of energy, which binds electron rotating around the nucleus (from the physics principals, a charge in motion produces a magnetic field) with its spin, which also induces a magnetic field. In this way, a non-ferromagnetic material, i.e., tungsten for example, can be a source of spin-polarized current, that will affect the magnetism of the other, adjacent ferromagnetic layers.

This spin current can also induce the so-called precession (rotation) of the magnetization. A typical oscillation frequency of the magnetization lies above 1 GHz, which is the range that is interesting from the signal transmission perspective or telecommunications. This behavior will be examined in particular in the context of the proposed project. Therefore, the aim of the project is the production and testing of spin electronic components of nanometer-sized dimensions, in terms of the spin-currents-induced dynamics in the microwave range.

The work was initiated by a leading group researching spinotrnics at Cornell University in the United States. In the publication: L. Liu et al. Science 336, 555 (2012) the Authors show that the platinum layer adjacent to a thin layer of an alloy of Co and Fe may be used to control the magnetism of the latter. This pioneering work triggered a number of studies on magnetism induced by spin currents generated from the spin-orbit interaction in heavy metals. The author of the project plans to focus on materials with high coupling, such as tungsten, iridium, tantalum, in order to maximize the interests of spin currents. In addition, the measurements of dynamic properties that can be used in practice, for example in telecommunication devices are planned. The research will be conducted in the international collaboration with leading Japanese Institute: AIST from Tsukuba, which has a unique equipment for the deposition of ultra-thin metal, insulating and ferromagnetic layers, which the author of the project worked with during his post-doctoral stay.

In addition, detection of microwave signals will be implemented using spin torque diode effect using: tunneling- (TMR), giant- (GMR) or anisotropic - (AMR) magnetoresistance. For their discovery of giant magnetoresistance two scientists: A. Fert and P. Grunberg were honored with the Nobel Prize in 2007. Using these phenomena it is planned to develop a new family of microwave devices, enabling the detection and generation of electromagnetic waves in the range of useful for telecommunications. For the realization of the research plans I plan to focus on the following tasks: generation and optimization of layered structures to maximize spin currents, static and dynamic measurement of electrical transport in fabricated micro- and nanostructures, theoretical modeling of dynamic systems spin currents induced. The experimental part of the project will include both a design and manufacture of thin film structures, as well as the study of structural and magnetic properties at continuous layers. Systematic study of various materials in the proximity of CoFe alloy layers were initiated with a partner in AIST and described in the recent publication: W. Skowronski et al. Phys. B 91, 184410 (2015). Then, the optimal systems are subject to extensive lithographic methods, which will result in the fabrication of spintronics nanodevices exhibiting appropriate electrical properties. The nano-lithography will be conducted at the Academic Center of Materials and Nanotechnology of AGH University, which is equipped with a technological lines installed in the cleanrooms (ISO5).

Systems will be thoroughly characterized in terms of static and dynamic properties such as the magnetoresistance ratio, the ratio of spin currents to the charge current (spin Hall angle), spin diode effect, spin-orbit-torque-induced ferromagnetic resonance control using an electric field. At every stage of the project, the proposed design and implementations will be supported by theoretical calculations and simulations.

Within the research project it is planned to use the spin current in order to implement a new class of dynamical systems. The innovations of the project include the use of spin-orbit coupling in heavy metals for the induction of the spin dynamics in the adjacent ferromagnetic layer. Then, I plan to develop prototype three-terminal device that uses voltage controlled magnetic anisotropy in order to create the microwave voltage-controlled oscillator. The advantage of three-devices and the use of systems with spin-orbit coupling is the ability to separate the charge and spin currents, which may affects the power consumption of electronic circuits and also reduces the risk of breakdown of used tunnel elements.

Using the spin electronics device, one can minimize the charge currents contribution at the cost of spin currents, which allow the reduction of the heat dissipated in the system. In addition, the use of microwave spintronics devices may further contribute to the reduction of power consumption of high frequency signals transmitters, for example, as they do not need captious inductive elements for operation. This will allow for an extension of the operation time of mobile devices using battery supply.