Abstract

Thin magnetic films and layered nanostructures are basic elements in fast growing magnetoelectronic (spintronic), which uses spin of electron in addition to its charge. Spintronic applications in information technology (MRAM – magnetic random access memory, GMR – giant magnetoresistance) rely on developement of thin film technology, which uses the spin-dependent electron transport with conventional electronics. These applications lead to devices operating at increasingly higher frequencies and miniaturization reaching submicron scale. Therefore, it is important to investigate and determine the magnetic properties of these structures in a high frequency range. In that aspect, for over fifty years, a recognized experimental technique is ferromagnetic resonance (FMR) which is a valuable tool for accurate characterization of properties of ferromagnetic materials, in particular thin film structures.

This thesis is devoted to research on the magnetization dynamics in series of layer structures using broadband FMR with Vector Network Analyzer (VNA). Broadband VNA-FMR spectrometer is a device that allows inductive measurement of magnetic permeability over a wide frequency range (up to several tens of GHz) and identify a number of aspects of the magnetization dynamics that are not available by using classical FMR. Coplanar waveguide (CPW) enables generation of microwave magnetic field in a wide frequency band from tens of MHz to GHz, in comparison to resonant cavity which is limited to one resonant frequency. It allows to perform measurements in frequency sweep mode without changing the magnetic configuration of the sample, eg. for measurements in small fields without changing the domain structure. Another important advantage of the VNA-FMR is possibility to obtain the dispersion relation $\omega(H)$ described by Kittel equations suitable for the nanostructures (eg. magnonic crystals). An important feature of the VNA-FMR is also possibility to precisely determine the damping parameter of spin excitations. With a possibility of independent setting of the magnetic field and the frequency, damping parameter can be quantitatively investigate by VNA-FMR and the „internal" contribution (associated with the Gilbert damping) and „external" (associated with structural defects) can be separated.

This doctoral thesis presents the results of VNA-FMR measurements of series of layered magnetic systems with different structures and varying thicknesses from ultrathin magnetic layers ($\approx$ 1 nm) to „thick" amorphous ribbons ($\approx$ 20 microns). Anisotropies associated with the surface of layers (unidirectional and perpendicular anisotropy) play a key role in ultrathin layers. Magnetization dynamics in systems with unidirectional anisotropy was described with the help of exemplary magnetic systems of Co/IrMn, NiFe/NiMn and Co_2FeSi/IrMn. It was also shown how to determine the rotatable anisotropy constant occurring in FM/AFM systems, whose presence increases the resonance frequency. Surface and volume perpendicular anisotropy parameters were determined by measurement of Co/Au, and CoFeB/MgO samples with a linear change in thickness of the FM layer (wedge). Coplanar waveguide measurements allow for local resonance measurements on the wedge sample and the determination of the effective magnetization dependence on the thickness of ferromagnetic material. Dual spin valves, consisting of a perpendicularly magnetized polarizer (Co/Au multilayer), the free layer (consisting of layers of NiFe and Co) and analyzer (Co layer coupled with a IrMn layer) were also prepared and characterized magnetically. Each of the subsystems differ in anisotropy, so FMR peaks are observed at other fields for each subsystem and their dynamics can be described separately. Furthermore, the individual subsystems have been seperated by a non-magnetic spacer so thick that there was no strong interactions between them, which allowed the analysis of the results on the basis of the results described in previous chapters.

The sample on the coplanar waveguide is exposed both to the magnetic and electric microwave field in contrary to the measurements in the microwave cavity, in which the sample is placed in a position where there is only a microwave magnetic field. Not all the consequences of this situation are known. It was observed for the first time that the VNA-FMR signal intensity increases with the decrease in resistance of buffer layer. This effect is explained by shielding of the magnetic and electric microwave field and trapping them in the space between coplanar waveguide and the conductive buffer layer.

In addition, this dissertation presents the first known VNA-FMR measurements of thick (tens of μm) amorphous ribbon. In such thick layers the phenomenon of ferromagnetic antiresonance occurs, due to increasing penetration depth of the electromagnetic wave in the ferromagnetic material. Maximum (ferromagnetic resonance) and minimum (ferromagnetic antiresonance) in absorption spectrum was observed for amorphous ribbon. Broadband VNA-FMR measurements allow to obtain dispersion relations of ferromagnetic resonance and antiresonance. The spectroscopic splitting factor g and the effective magnetization can be evaluated with a high accuracy using these relations.

This thesis is characterized by three main aspects related to the experimental physics of magnetism in thin layers: building the first broadband ferromagnetic resonance VNA-FMR setup in Poland, preparing a range of thin film structures using high vacuum technology and characterization of magnetization dynamics in these structures.