Fe/Ni thin films temperature investigation with MgO and SiO₂ interfaces by ferromagnetic resonance

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Abstract. In this work the temperature study of magnetic – resonance properties of the structures such as Fe/MgO/Ni, Fe/SiO₂/Ni differing thickness of spacer and of method of preparation was carried out by FMR. These systems are investigated to estimate their applicability in model creation experiments for a spintronics devices research [1-4]. The special attention was given to the temperature dependence research of three layer films linewidths. The out-of-plane temperature dependences of FMR signal position and linewidths have been measured for Fe/Ni samples with MgO and Si/SiO₂ interfaces in static position of 0 and 90 degrees rotation angle to the external static magnetic field. The extracted magnetic parameters such as linewidths and resonance field position were studied.

1. Introduction
The study of ferromagnetic resonance (FMR) linewidth of multilayer structure is a useful diagnostic of the quality of the structures developed for a variety of applications [5] and exchange coupling between ferromagnetic layers across the nonmagnetic spacer [5] for different structures with Fe and Si content. One of the important problems today is a development of new materials and combinations for applications in field of spintronics. A lot of alloys and structures were investigated today for applicability of spintronics and microelectronics devices research. Fe₁₋ₓMnx alloys had been studied for «spin valve» devices application in [6] and suggest about foundation of different phases in nanoscale particles with various magnetic properties. Temperature dependent magnetization dynamics in thin FeNi layers in contact with an antiferromagnetic NiO were observed by J. Dubovik [7]. The anomalous broadening of linewidth and negative lineshift were observed for in-plane and out-of-plane geometry at ~150K temperature.

At the other hand, there is a great interest in the magnetization dynamics of magnetic multilayers because of their potential applications non-volatile magnetic random access memory and microwave devices. In the field of MRAM, much effort has been devoted to decreasing power consumption through the use of current-induced magnetization. [8]. Experimentally it was shown, that current-induced magnetization was observed as the current perpendicular to planetype giant magnetoresistivity of a nanopillar, in which the spin-polarized current injected from the fixed layer exerts a torque on the magnetization of the free layer. The torque induced by the spin current is utilized to generate microwaves.

The Gilbert damping constant is an important parameter for spin electronics since the critical current density of CIMR is proportional to the Gilbert damping constant [9, 10] and fast-switching
time magnetization reversal is achieved for a large Gilbert damping constant [11]. Several mechanisms intrinsic to ferromagnetic materials, such as phonon drag [9] and spinorbit coupling [10], have been proposed to account for the origin of the Gilbert damping constant. In addition to these intrinsic mechanisms, Mizukami et al.[11, 12] and Tserkovnyak et al.[13, 14] showed that the Gilbert damping constant in a non-magnet (N) / ferromagnet (F) non-magnet (N) trilayer system is enhanced due to spin pumping. Tserkovnyak et al. [16] also studied spin pumping in a collinear F/N/F trilayer system and showed that enhancement of the Gilbert damping constant depends on the precession angle of the magnetization of the free layer [8].

To analyze magnetic and transport properties it was suggested to use different interface layers at the formation process of Fe/Ni thin films, e.g. SiO₂ and MgO. In this work we report FMR study of the magnetic properties of the Fe/MgO/Ni, Fe/SiO₂/Ni systems realized in a polycrystalline 3-layer structures to assess their applicability in a functional magnetic tunnel junction.

2. Experimental details

The samples in this work such as Fe/SiO₂/Ni were synthesized by ion-plasma deposition technique, deposited on substrate with high energy ion beam, and Fe/MgO/Ni formatted by pulsed laser deposition on also RT amorphous Si/SiO₂ substrate. The spacer layer thickness were varied from 1 to 50 nm, making possible establishment exchange interaction properties between magnetic Fe and Ni layers by FMR.

Ferromagnetic resonance spectra of the films were taken using Bruker electron spin resonance spectrometer with temperature module. Experiment was held at the X-band frequency 9.5 GHz and the modulation frequency 100 kHz. The first field derivative of the microwave power absorption was registered as a function of applied steady magnetic field at the different temperature.

The out-of-plane dependences of FMR spectra and linewidths have been measured for two samples. Samples were investigated at 80K – 273K for Fe/SiO₂/Ni and at 10K – 273K for Fe/MgO/Ni. The extracted magnetic parameters such as the linewidths, effective magnetization, resonance field position were studied.

3. Results

FMR signals were analyzed at different samples orientation relatively to the external static magnetic field at different temperature in position of 0 and 90° Fe/SiO₂/Ni and in position of 90° for Fe/MgO/Ni degrees rotation angle to the external static magnetic field at 80K – 273K for Fe/SiO₂/Ni and at 10K – 273K for Fe/MgO/Ni. The experimental results are presented at the table 1 and figures 1, 2.

| №  | Sample structure, synthesized on Si/SiO₂ | ΔB, G | B res, G |
|----|----------------------------------------|-------|---------|
| 1  | Fe/SiO₂/Ni                             | 143   | 8885,5  |
|    |                                        | 143   | 8400,5  |
| 2  | Fe/MgO/Ni                              | 1854  | 9399    |

The FMR research of Si/SiO₂/Fe/SiO₂/Ni and Si/SiO₂/Fe/MgO/Ni structures (sample №1 in table 1) showed that the spectrum parameters depends on temperature and rotation angle to the external static magnetic field. Two signals were observed for Si/SiO₂/Fe/SiO₂/Ni: the narrow high intense signal in area $B_{res} = 8885,5$ G with the line width $ΔB = 143$ G, which depend on the temperature, and the narrow weak signal with the intense lower by one order of magnitude, with resonance field and line width depends on the temperature. Such signal behavior points at the presence of two magnetic
phases in this sample. Temperature dependence of the FMR signal position data we obtained correlate with J. Kienert et al. [16] data for FMR signal position and number of modes for Ni thin films.

For the sample (table 1, sample №2) with MgO interface Si/SiO2/Fe/MgO/Ni sample one ferromagnetic signal was observed, the position and linewidths of which depend on the temperature. Dramatically changes in temperature (from 273 K to 80 K) of the sample with MgO interface are confirmed by the significantly FMR signal position changes. It was suggested to Si/SiO2/Fe/SiO2/Ni sample as a material for model experiments for magnetic tunneling junctions development, because of coincidence with [16] FMR resonance field behavior.

On figure 1. FMR signal position (a) and linewidth (b) for sample with Si/SiO2/Fe/SiO2/Ni structure are shown (sample №1 (table 1). FMR modes 1 and 2 [5] (figure 1a) are interested as they had steady shift into lower fields parallel to each other. It may be used as sample quality evidence for Si/SiO2/Fe/SiO2/Ni structure. On figure 1b we obtained linewidth temperature dependence for both modes of signal. It has a symmetric behavior. We have coincidence of temperatures at 160 K to 220 K for modes 1 and 2. We suggest that it caused by thickness of Si/SiO2/Fe/SiO2/Ni layers structure. We have the same gradual behavior of FMR signal position as at [5] for Ni structures, but for linewidth behavior is different.

On figure 2. FMR signal position (a) and linewidth (b) for sample with Si/SiO2/Fe/MgO/Ni structure for FMR signal mode. We have 273 K – 10 K temperature diapason for FMR signal position (figure 1a) and linewidth (figure 2a). We have intensive shift of signal position from 220K to 100K into lower fields and slow anomalous shift from 100K to 70K. Then we have signal position shift into the lower fields until 10 K. Lifewidth also begun to rise after the point of 100 K temperature. The same behavior for FMR Signal position from temperature we have in [6] for 300 – 500 K temperature range, but in [7] we have gradual lowered temperature dependence for NiO thin films, without any shape shifts. Linewidth dependence results correlates with [6] for sample heating process.

Figure 1. FMR signal position (a) and linewidth (b) for sample with Si/SiO2/Fe/SiO2/Ni structure: FMR signal mode 1 and signal mode 2 are shown.
Figure 2. FMR signal position (a) and linewidth (b) for sample with Si/SiO₂/Fe/MgO/Ni structure: FMR signal mode is shown

4. Summary
In this work the experimental temperature study of magnetic properties of the Si/SiO₂/Fe/SiO₂/Ni and Si/SiO₂/Fe/MgO/Ni systems realized in a polycrystalline structures was made by ferromagnetic resonance (FMR) technique at different temperature. The investigations of magnetic properties of different multilayer structures, grown up on Si/SiO₂ substrate by FMR, were done. The analysis showed that parameters of FMR spectra of multilayer structure are very sensitively to the arrangement of temperature and nature of the interface material. Such systems are interesting because of behavior of spectrum parameters dependent of temperature become more clear. Work [15] illustrates the same data behavior of FMR parameters and correlate with our data.

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