Four-point probe stand for magnetoresistance measurement of unpatterned sample

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Abstract. An experimental stand for express diagnostics of multilayer spin tunnel structures has been developed. The current-in-plane tunnelling method (CIPT) requires no processing, is fast, and provides reliable data which are reflective of the deposition only. The stand is based on the four-probe method for measuring resistance at external alternating magnetic field. This technique can be applied after only a short processing route, thereby saving time and resources, and reducing the potential for damaging the junction.

1. Introduction
Magnetic Tunnel Junction (MTJ) is an important element of modern MRAM cell. It is believed that MRAM might be the next generation of computer memory [1]. Therefore optimization of the technology for MTJ fabrication is very important task. Standard spin-tunnel structure used to make MTJ consists of two magnetic layers separated by the layer of tunnel dielectric. MTJ fabrication involves complex technological route consisting of deposition of multilayer structure and subsequent MTJ pattern formation through lithography. Achievement of high functional characteristics of MTJ requires intensive quality control at different stages of the technological route [2]. This article describes a non-destructive quality control method for a multilayer spin tunnel structure capable of weeding out rejected wafers prior to production. This method is also suitable for controlling spin-valve structures, measuring AMR, etc. Typically, to control the magnetoresistive effect, the spin tunnel structure is prepared by providing contact pads to the lower conductive bus and the upper layer. The process consists of more than ten technological steps and this preparation may be unsuccessful. Possible solution to that problem is the current-in-plane tunneling method (CIPT) being proposed in the paper [3]. This method is fast, requires no processing, and provides reliable data which are reflective of the deposition only and is currently widely used in modern MRAM production. In this work simplified version of the method is proposed. Unlike the original version of CIPT method present realization uses relatively large probe spacing (about 1 mm) and high amplitude probe current (about 1A).

2. Measuring stand
Magnetoresistive effect represents a change in the resistance of a structure in an alternating magnetic field. The resistance of such structure depends on the mutual magnetization of the magnetic layers. For example, if the magnetizations of two layers are codirectional, the resistance of such structure is low, and if the magnetizations are oppositely directed, the resistance is large [1].
The measuring stand consists of two electrical circuits (Figure 1). The first circuit is designed to create an alternating magnetic field and includes a frequency generator, an amplifier, a capacitor, and Helmholtz coil. To ensure the maximum amplitude of the current in the coils, the generator must provide a resonance in the LC circuit, which occurs at a frequency of 20 Hz. At this conditions Helmholtz coil creates a field of about 10 mT. The second circuit is designed for four-probe resistance measurement and consists of a DC source and a measuring head with probes. Standard spring-loaded pogo pins are used as the probes.

![Figure 1. Scheme of the stand.](image)

The measuring stand includes a 4-point probe being in a contact to the sample surface placed in an alternating magnetic field. A probe current is applied to two outer contacts, and the voltage is measured on the two middle contacts. At this stage of development, three probe heads with contact distances of 2.5 mm, 2 mm, 1.6 mm have been prepared. Work is underway to switch to submillimeter sizes. The measured signal is processed on a computer. For this, a program written in the LabVIEW development environment is used.

Figure 2 shows a diagram of the current flow through the sample and a simplified equivalent circuit. Two horizontal resistors represent currents passing in layers and two vertical resistors represent interlayer currents passing through tunnel barrier. The depth of current flow depends on the distance between the contacts. The signal proportional to the interlayer current increases as the probes approach each other. The effect of tunneling magnetoresistance is manifested in a change in the value of the vertical resistors in the equivalent circuit in an external magnetic field.

![Figure 2. Diagram of the current flow through the sample and the equivalent circuit.](image)
In the papers [3, 4] it has been shown that magnetoresistance effect can be observed if the distance between contacts is around 5-10 microns. But at present version of the described measuring stand the effect can be observed even for the distance between the contacts of about 1 mm. This is achieved by the use of relatively high probe current about 1 A. However, such a large current imposes a limit on the measurement time to prevent overheating of the sample.

There are two assumptions that can explain the observation of the magnetoresistive effect at such a large distance between the contacts. The first assumption is related to the phenomenon of electric current spreading over the surface and over the layers. The second is the heating of the sample when a large current flows through it, which changes the resistance of the layers and makes it possible to observe the effect at large distances.

3. Results

Measurements to control the magnetoresistive effects were carried out using probes with different distances between the contacts. The stand has three measuring heads with contact distances of 2.5 mm, 2 mm, 1.5 mm. Each of them is able to detect the change in resistance in an alternating magnetic field. The samples for measurements were standard spin tunnel structures provided by Crocus Nanoelectronics [2]. Their tunneling magnetoresistance (TMR) value was estimated using CIPT method on CAPRES equipment to be around 140%.

Figures 3, 4 show resistivity versus magnetic field curves for the distances between the contacts of 2.5 mm measured for different orientations of external magnetic field. During the measurement in Figure 3, magnetization occurs along the easy magnetization axis. As a result of measuring the change in resistance in an external magnetic field, a hysteresis loop was obtained for a soft magnetic layer. For complete magnetization reversal of the soft magnetic layer, it is necessary to apply an external magnetic field of about 6 mT. This result is confirmed by earlier studies of the magneto-optical Kerr effect of the same sample. To make sure that the loop obtained in the figure is the effect of tunneling magnetoresistance, it is enough to rotate the sample by 90°. When turning, the external magnetic field becomes directed along the hard axis of magnetization. In this case, magnetization reversal curve change shape. The result of this measurement is shown in Figure 4.

![Figure 3. Hysteresis loop for external magnetic field along the easy axis.](image-url)
4. Conclusion
At the moment, the stand is designed, assembled and tested on a spin-tunnel structure. This stand has shown its efficiency. Thanks to it, it is possible to carry out express diagnostics of structures for the presence of magnetoresistive effects. Unlike the original version of CIPT method present realization uses relatively large probe spacing (about 1 mm) and high amplitude probe current (about 1A). The measurement of the signal for different sample orientations, clearly shows the direction of the easy axis of the structure. It confirms possibility of magnetoresistance measurement at such conditions. The work on the stand improvement and debugging is still underway.

Acknowledgments
This work was carried out on the equipment of the centre for collective use of scientific equipment "Diagnostics of micro- and nanostructures" within the framework of the State assignment of the P.I. K.A. Valiev RAS Ministry of Education and Science of the Russian Federation on topic No. 0066-2019-0003 "Fundamental and applied research in the field of creating promising instrument nanostructures for storing information on new physical principles".

The work was carried out with the support of the Federal State Budgetary Institution "Fund for Assistance to the Development of Small Forms of Enterprises in the Scientific and Technical Sphere" (contract No. 14947ГУ/2019 dated 20.12.2019).

References
[1] Fert A 2008 UFN 178 12 1336
[2] Trushin O S, Simakin S G, Vasiliev S V and Smirnov E A 2018 Russian Microelectronics 47 6 381
[3] Worledge D and Trouilloud D L 2003 J. App. Phys. Lett. 83 84
[4] Christian L Peterseny, Rong Linz, Dirch H Petersenz and Peter F Nielsenz 2006 2006 14th IEEE International Conference on Advanced Thermal Processing of Semiconductors 9431599

Figure 4. Hysteresis loop for external magnetic field along the hard axis.