Measuring Unit for the Observation of Hysteresis Loops in Thin Ferromagnetic Films

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***Abstract*—The magnetic properties of thin magnetic films are of scientific and practical promise due to their of the physical properties. The presence of hysteresis loops is the specific characteristic feature of ferromagnetic materials. Some magnetic characteristics, as well as the quality of a thin ferromagnetic film can be determined by the hysteresis loop. The paper considers a new measuring unit for the observation of hysteresis loops in thin ferromagnetic films. A structural scheme, a sketch of the measuring unit, an external appearance are presented. Two Hall sensors were used as a sensitive element. Detailed description of the design is given and the advantages of the new unit over its analogues are shown. The results of the experiment confirm that the newly developed measuring unit can be used to solve various scientific and practical problems, e. g., for the express measurement analysis of hysteresis loops in thin magnetic film device manufacturing. The experiment was carried out on a thin ferromagnetic film of permalloy $Ni_{80}Fe_{20}$ composition with 8 magnetic layers. The sample was obtained by magnetron sputtering of a permalloy target on a glass substrate in vacuum. The dimensions of the film were 4 × 8 mm.**

The new measuring unit allows to use any external sources of alternating magnetic field. The sensitive elements (Hall sensors) of the unit can be replaced by other magnetic field sensors.

Keywords—thin magnetic films, measuring unit, magnetic characteristics, hysteresis loop

I. Introduction

The magnetic properties of thin magnetic films (TMF) are of scientific and practical promise due to their of the physical properties [1]. TMF are used as memory elements to store high-capacity information and as a material for microwave integrated circuits. Sensitive sensors, microwave attenuators and phase shifters controlled by a magnetic field, frequency-selective elements for communication and radar systems have been developed on the basis of TMF. TMF are used as effective protective and absorbing coatings [2, 3].

The presence of hysteresis loops is the specific characteristic feature of ferromagnetic materials. The main characteristics (parameters) of the loop are: saturation magnetization J_s, remanent magnetization J_r, coercive field H_c, magnetic anisotropy field H_k, and loop area S. The J_r, H_c, S values are structure-sensitive parameters. The J_r, H_c, S values can be changed by various material treatments (mechanical, thermal, thermomagnetic, etc.) within wide limits. The field of technology in which a magnetic material is used depends on the values of the hysteresis parameters [4], e. g., the lowest possible H_c value is required for the soft magnetic materials, and for the hard magnetic materials – the highest possible H_c.

The characteristics and reliability of devices on the basis of TMF depends on the quality of the film. It is important to control the quality of TMF magnetic characteristics for the testing of TMF production technology, as well as for the manufacturing process. A ferrometer is a device for measuring the magnetic characteristics of thin ferromagnetic films by using hysteresis loops. Thus, the development of a unit for observation of hysteresis loops in thin ferromagnetic films is an essential task. R. F. Soohoo described a device for observing the dependence of the magnetization of a sample on the applied field: a looper [5]. The looper design (Fig. 1) uses several small coils with a large number of turns. The sensitivity of the device is proportional to the number of turns in the coils, so there is a need to increase the number of turns and to decrease the wire diameter. Such coils are difficult to manufacture, and the sensitivity of the device depends on their quality. In addition, the design of the looper presented by R. F. Soohoo contains an integrator that is difficult to implement with high quality. Also, the design of the looper requires its own source of the remagnetization field, e. g., calibrated Helmholtz coils.

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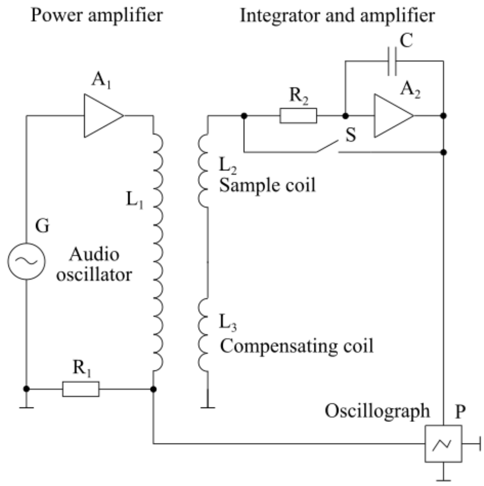

Fig. 1. Block diagram of the looper, given by R. F. Soohoo in [5]

A new measuring unit was proposed to observe the hysteresis loop of a thin ferromagnetic film. This unit has a simplified design. By observing the TMF hysteresis loop we determined the magnetic characteristics, as well as the quality of the test sample.

II. The Design of the Measuring Unit

The new measuring unit includes a printed circuit board, Helmholtz coils, a low frequency (LF) current oscillator, a power supply, and an oscillograph or digital recorder (Fig. 2).

Fig. 2. Measuring unit for the observation of hysteresis loops in thin ferromagnetic films

The printed circuit board is connected to a power supply. Helmholtz coils are connected to a LF current oscillator and are used to create an alternating magnetic field. It is possible to use any external remagnetization magnetic field source. The direction of the alternating magnetic field coincides with the direction of maximum sensitivity of Hall sensor no. 3. The output signal from Hall sensor no. 3 goes to the operational amplifier, which acts as a low-pass filter (LPF) and then to the output connector. Therefore, the signal at the output of the connector is directly proportional to the magnitude of the test sample remagnetization field. From the output connector, the signal is fed to the horizontal input of an oscillograph or any digital recorder. The test sample is placed on a sensitive element, which consists of two Hall sensors (positions 4, 5 in Fig. 3). The axes of the sensors are located perpendicular to the direction of the remagnetization field and perpendicular to the TMF plane. The signal of the first Hall sensor is inverted and applied to the input of the adder. Signal from the second Hall sensor is fed to the second input of the adder. The output signal of the adder is fed to the output connector and then to the vertical input of the oscillograph or digital recorder.

In Fig. 3 shows a structural scheme and a unit sketch of a new measuring unit for the observation of hysteresis loops in thin ferromagnetic films.

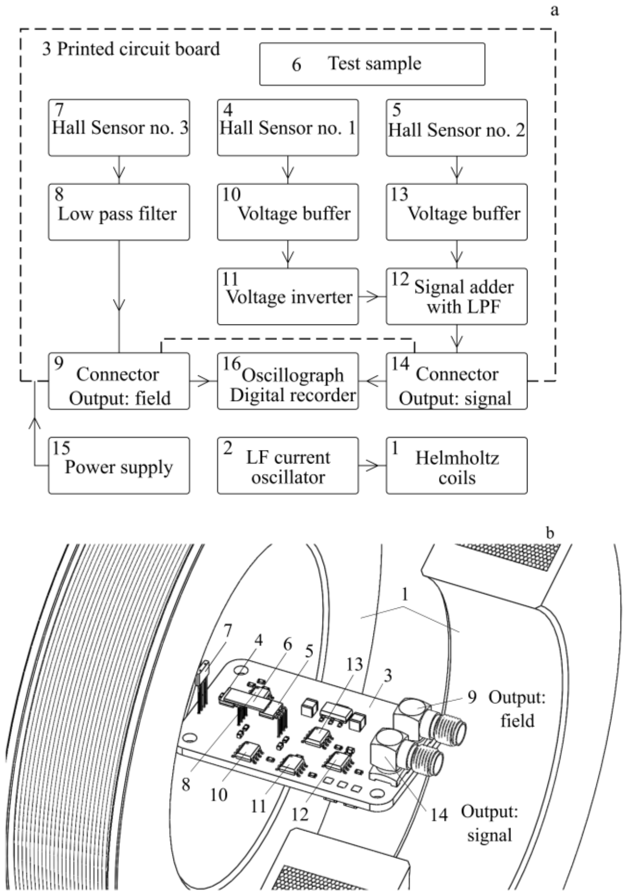

Fig. 3. Measuring unit for the observation of hysteresis loops in thin ferromagnetic films: a – structural scheme, b – unit sketch

III. Measurement Procedure

The test sample is placed over the sensitive element. The axes of the Hall sensors should be directed perpendicular to the direction of the remagnetization field and perpendicular to the plane of the TMF. An alternating magnetic field is created by Helmholtz coils, which are connected to the LF current oscillator. The printed circuit board is powered on. From the output connector (position 9 in Fig. 3) the signal is fed to the horizontal input of the oscillograph or digital recorder, and from the output connector (position 14 in Fig. 3) – to the vertical input. The oscillograph (digital recorder) displays a hysteresis loop. By rotating the test sample, hysteresis loops can be observed for different remagnetization directions of the sample. Measurement results are saved as images and raw data files. The obtained loops are used to determine the magnetic characteristics of the test sample: saturation magnetization J_s, remanent magnetization J_r, coercive field H_c, magnetic anisotropy field H_k, and loop area S. By the type of the hysteresis loop, one can estimate its rectangularity along the easy magnetization axis (EA), as well as the collapse of the loop along the hard magnetization axis (HA).

A printed circuit board with a thin ferromagnetic film is shown in Fig. 4. The board is connected to a power supply and an oscillograph (digital recorder).

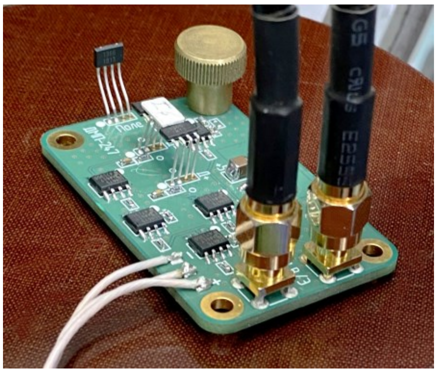

Fig. 4. Printed circuit board of a new unit for observing hysteresis loops of thin ferromagnetic films

IV. Experiment Results

The experiment was carried out according to the indicated procedure on a thin ferromagnetic film of permalloy $Ni_{80}Fe_{20}$ composition with 8 magnetic layers 1000 Å thick. The sample was obtained by magnetron sputtering of a permalloy target on the glass substrate in vacuum. The permalloy deposition was carried out under ~200 Oe magnetic field in the film plane. The film has dimensions of 4 × 8 mm. The results of measurements during remagnetization along the EA are shown in Fig. 5. The first curve shows signal from the Hall sensor no. 3, that represents magnetic field strength. The second curve shows signal from adder of measuring unit, which is proportional to the sample magnetization. The third curve is X-Y graph of the first and the second signals. This curve is the hysteresis loop of the test sample. To conduct precise measurements, it is very important to orientate Hall sensors no. 1 and no. 2 so that their sensitivity axis should be orthogonal to the remagnetization field. In this case interfering signal from remagnetization field will be minimized.

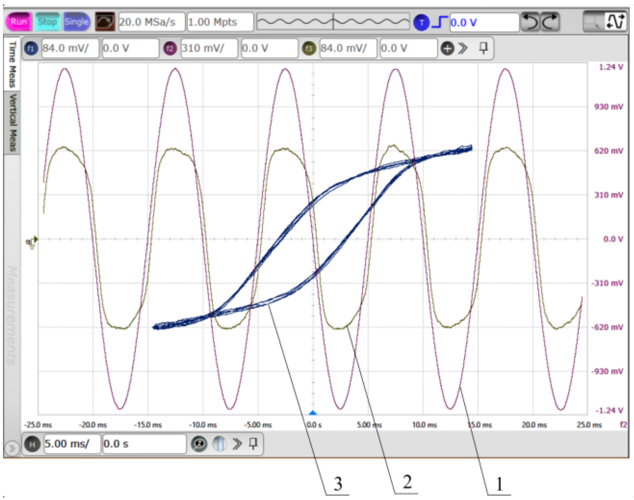

Fig. 5. Hysteresis loop of a thin ferromagnetic film upon remagnetization along the EA of the $Ni_{80}Fe_{20}$ sample: 1 – signal from the Hall sensor no. 3; 2 – signal from adder of measuring unit; 3 – hysteresis loop of the test sample

From the obtained hysteresis loops the coercive field H_c=1.1 Oe. Also, the magnetic anisotropy field was determined, which is H_k=8 Oe. The measurement results coincide with an accuracy of ±5% with the results of measurements on a scanning ferromagnetic resonance spectrometer [2]. By rotating the test sample, it appeared to be magnetouniaxial. When an external field was applied along the EA, the hysteresis loop had rounded corners. When an external field was applied along the HA, perpendicular to the EA, the width of the hysteresis loop was almost zero, i. e. it collapsed. From the obtained hysteresis loops along EA and HA, one can obtain a curve that allows one to study in detail the behavior of the film magnetization vector in an external magnetic field. This curve represents the astroid [6].

V. Conclusion

A new measuring unit for the observation of hysteresis loops in thin ferromagnetic films makes it possible to assess the quality of TMF fabrication and to determine some magnetic characteristics from the hysteresis loop. The unit has an alternating magnetic field range of ±250 Oe. Remagnetization occurs at a frequency of 100 Hz. The sensitivity of the new measuring unit makes it possible to measure the magnetic characteristics of thin-film materials with a thickness of more than 100 Å.

The advantage of the new measuring unit for the observation of hysteresis loops in thin ferromagnetic films, in contrast to the device described by R. F. Soohoo [5], is its easy manufacturing. It is achieved by avoiding the small coils of the sensitive element with a large number of turns and the absence of an integrator. New measuring unit has lower sensitivity due to Hall sensors. The magnitude of the alternating magnetic field is measured by the Hall sensor no. 3, which allows using of any external sources of alternating magnetic field in the new measuring unit. The printed circuit board has dimensions of 35 × 55 mm. The disadvantage of the new measuring unit is the dependence on the geometric dimensions (length and width) of the test sample: edges of the film must be located near Hall sensors. The dimensions of the TMF must be less than 6 × 12 mm. The proposed simple measuring unit can be used for express hysteresis loop measurements for the thin magnetic film device manufacturing. The sensitive elements of the unit can be replaced by other magnetic field sensors.

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