Magnetoresistive-based static tester for actuators

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A static tester for precision actuators is proposed. It is intended to test the functioning of future actuators to be used in hard drive read heads. The design allows a simple fabrication of a nanometer-scale position measurement system that can measure lateral, vertical, and angular displacements. The tester consists of (a) a reference magnetic layer of CoCrPt, ($150 \times 100\ \mu m^2$, 600 nm thick) and (b) a sequence of four spin-valve sensors. The tested sensors have crossed anisotropies, 6.9% magnetoresistance with a linear response, 0.5%/mT sensitivity, coercive field less than 0.1 mT and resistance of 1680 Ω in the parallel state. A noise level of 6 nV/$\sqrt{\text{Hz}}$ was measured at thermal background for 0.2 mA of applied current. The lateral displacement is measured by the two spin valves in the center. While the magnetic element is passing over these sensors, the measured signal on each of them varies in opposite directions, allowing a precise measurement of the center position. The two outer spin valves are sensitive to the angular orientation of the magnetic element. The relative movements of the spin valves and magnetic element are controlled by computer using piezoelectric crystals and step motors. Since the sensors are measuring the in-plane component of the field, the signal measured decreases rapidly with sensor-to-plane distance. An appropriate range for flight height is about 30 μm. Simulations of the signal are in agreement with measurements. © *2008 American Institute of Physics*.
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Hard disk drives have become major storage devices in computer technology. Its storage density has increased for several decades.[1] In order to go on with the storage density roadmap,[2] it is necessary to reduce the track dimensions below 100 nm. This requires precision second-stage actuators,[3] based either on coils, microelectromechanical system technology[4] or electrostatic actuation.[5] In this letter, the realization of a magnetoresistive sensor-based static tester for precision track actuators is reported. The goals are to measure relative lateral displacement in one direction with a nanometric precision and out-of-plane actuator rotation with a precision of 0.1°.

The implemented static tester uses four spin-valve sensors with the following structure: Si/Al_2O_3 (50 nm)/vacuum break/Ta (2 nm)/NiFe (3 nm)/CoFe (2.4 nm)/Cu (2.2 nm)/ rotation 90° under vacuum/CoFe (2 nm)/MnIr (8 nm)/Ta (2 nm)/vacuum break/TiW(N) (15 nm). Here, NiFe, CoFe, and MnIr stand for the alloys of atomic composition $Ni_{80}Fe_{20}$, $Co_{82}Fe_{18}$, and $Mn_{77}Ir_{23}$, respectively. The TiW(N) layer serves as an antireflective coating. The spin valves were deposited in a Nordiko 3000 ion-beam deposition system with a base pressure of 16×10^{-6} Pa. These samples were deposited with crossed anisotropies.[7] A field of 4 mT was applied to induce the anisotropy of the free and pinned layers. The sample was rotated 90° in between the deposition of the two layers. This allows the elaboration of sensors that show a linear response as function of field. Since a magnetic field was applied during the deposition, this top-pinned spin-valve structure does not require a postdeposition annealing. Furthermore, the annealing, which would help the alignment of the anisotropies of the MnIr antiferromagnetic layer and the CoFe ferromagnetic layer and increase slightly the magnetoresistance, would destroy the crossed anisotropy.

The spin-valve sensors were patterned by optical lithography to $2 \times 100\ \mu m^2$. The small dimension of the spin valve is parallel to the pinned direction. Spin valves show 6.9% of magnetoresistance and coercive field lower than 0.1 mT, as shown in Fig. 1(a). The noise level has been measured. The measurement setup, described in Ref. 8, was used with a

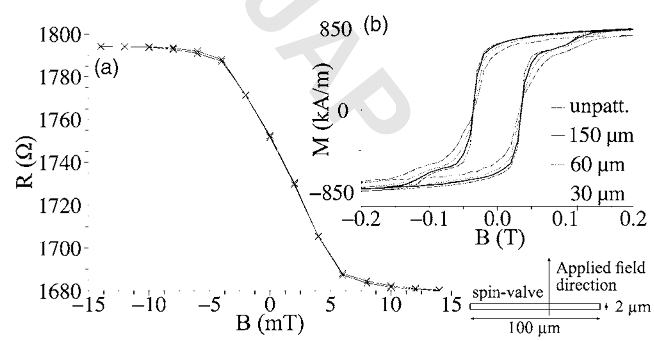

FIG. 1. (a) Hysteresis cycle of the spin-valve sensors used, showing a linear behavior with a magnetoresistance effect of 6.9%. The current applied for the measuremen was 0.2 mA. The inset (b) shows hysteresis cycle of the magnetic reference element, for an unpatterned sample and for different patterned sizes. The sample deposited on glass patterned, respectively, with rectangles of 100 μm(150,60,30 μm).

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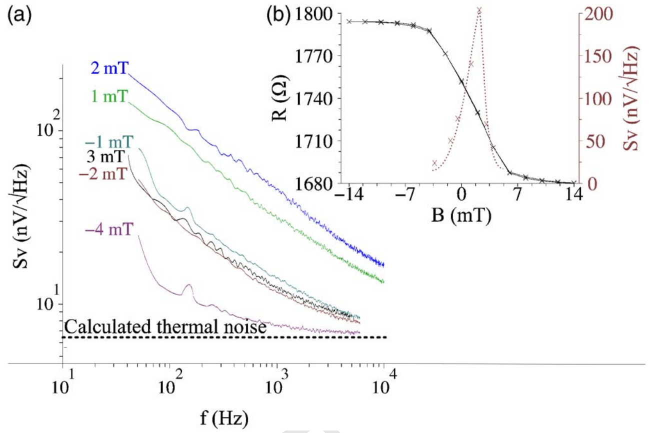

FIG. 2. (Color online) (a) Noise measurement of used sensors, measured at room temperature for a current of 0.2 mA and a resolution bandwidth of 20 Hz. Inset (b) shows the level of low frequency (30 Hz) noise superimposed with the hysteresis curve. Continuous line is a guide for the eyes.

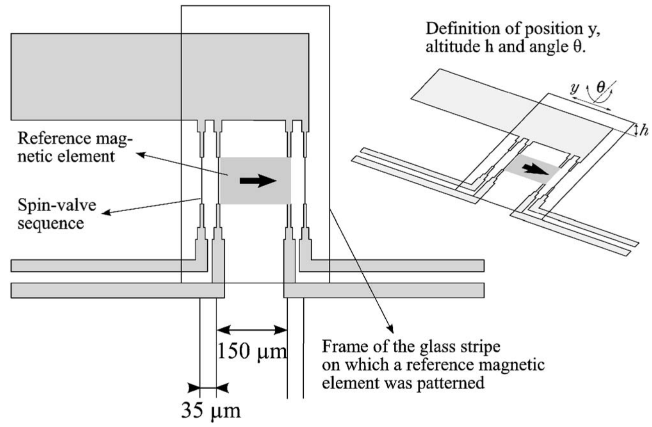

FIG. 3. Design of the spin-valve sensors. The magnetic reference element, of $100\times150\ \mu m^2$ can be seen on top of the spin valves, with an arrow indicating its magnetization direction. In the inset, definition of the coordinates y (lateral position), h (altitude), and θ (angle). The illustrations correspond to the horizontal geometry of measurement.

SRS SIM910 pre-amplifier, better suited to a base signal higher than 300 mV. Figure 2 shows a maximum noise for an applied field about 2 mT (in the center region of the hysteresis curve), where the sensitivity of the spin valve is highest. The noise in the low frequency range (30 Hz) was about 200 nV/$\sqrt{}$Hz. The thermal noise background, extrapolated from the 2 mT curve, is evaluated to 6 nV/$\sqrt{}$Hz.

In order to evaluate the static tester, a permanent magnet (PM) element was microfabricated and placed at a controlled altitude (distance between the sensor plane and the magnetic element plane) and in-plane position with respect to the spin-valve sensor array. The PM was deposited in an Alcatel SCM 450 sputter system, with the following structure: glass/SiO_2 (5 nm)/[CoCrPt (75 nm)/SiO_2 (5 nm)$]_8$. The atomic composition of the magnetic layer is $Co_{66}Cr_{16}Pt_{18}$.

The PM material used for the reference micromagnet was characterized by vibrating sample magnetometry. The measurement [Fig. 1(b)] shows a saturation magnetization of 800 kA/m, a coercive field of about 36 mT, and a remanent magnetization of $0.75\times M_s$.

The tester consists of two parts, one static and one moving. The static part is a holder for the reference magnetic element or magnetoresistive head. Two measurement geometries are possible. In the horizontal geometry, the tested element is glued on the bottom of a glass stripe. It allows a manual alignment through a microscope, provided that the substrate is transparent. In the vertical measurement geometry, the magnetic reference element as well as the spin-valve sensors lay in the vertical plane. The magnetic reference element is held by its back side, leaving the bottom part of the magnetoresistive head free for an air-bearing suspension. The moving part holds the four sensors. The geometry and definition of variables are given in Fig. 3.

The static tester was characterized by moving the sensor array across the stationary test micromagnet bar and detecting the stray field measured at the four spin valves. The result of this experiment is shown in Fig. 4(a). When the magnetic element is away from the sensor array, the signal is at its reference value. Signal changes as the magnetic element is approaching the sensors. When the border of the magnetic element passes on top of one of the spin-valve sensors, the measured change in voltage inverts its sign.

The space between the two center spin valves has been set equal to the size of the magnetic reference element. When

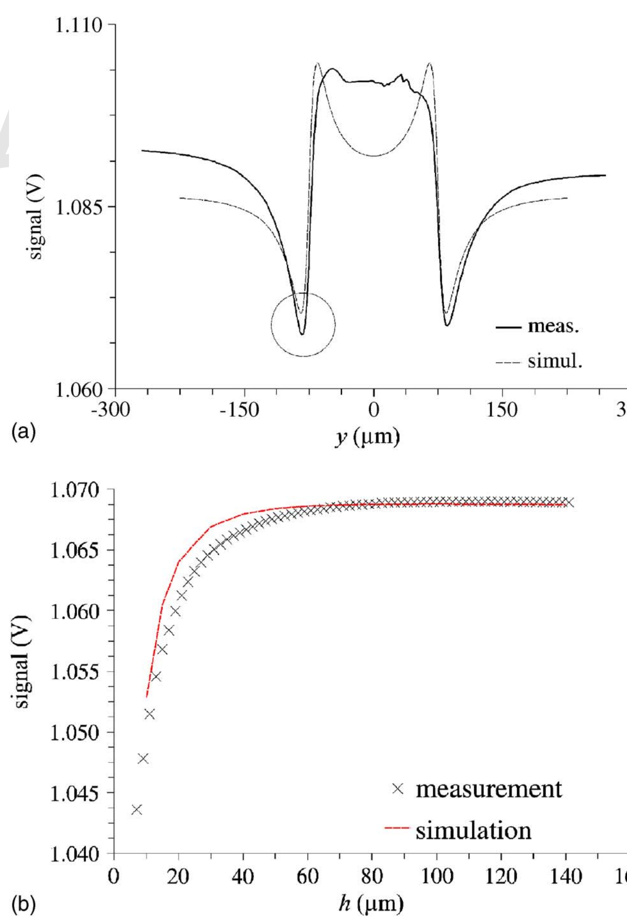

FIG. 4. (Color online) Simulated and measured output. (a) Measurement of the signal of a spin valve when the reference element is passing over for it, for a full-range measurement. The circled area corresponds to a zone where the variation of signal is highest signal change with the altitude of the reference element. (b) An approach made in the circled area, where the altitude h is changed between 5 and 160 μm.

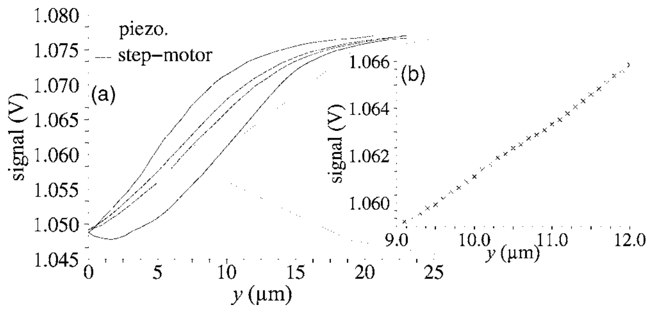

FIG. 5. (a) Experimental scan in the sensitive area (zone where the signal changes fast while the reference element is moved over the sensors), using a piezoelectric actuator and a step motor. The hysteresis opening shown comes from the actuation mechanism. The inset (b) shows in detail the output for a movement by steps of 0.1 μm.

the element is centered on top of spin valves, each of its two borders is exactly above one spin valve. This way, when the element is moving laterally, its two borders go above both of the spin valves, which sense a change of field with opposite signs.

When the magnetic reference element passes over the sensors, the total signal amplitude for the conditions used for the measurement ($I=0.6$ mA, $R=1800\ \Omega$, $h=20\ \mu$m) is about 30 mV. The 30 mV variation requires a movement of 40 μm. The sensitivity when the sensor is centered is about 1.5 mV/μm. This allows to detect movements smaller than 100 nm, as shown in the inset of Fig. 5. The signal to noise ratio can be defined as $\mathrm{SNR}=S\Delta y/\sqrt{((S_v^{\mathrm{th}})^2+(S_v^{1/f}-S_v^{\mathrm{th}})^2(I/I_0)^2)\Delta f}$, where $S_v^{1/f}=200$ nV/$\sqrt{\mathrm{Hz}}$ is the noise in the low frequency range (30 Hz), $S_v^{\mathrm{th}}=6$ nV/$\sqrt{\mathrm{Hz}}$ is the thermal noise, $\Delta f=20$ Hz is the resolution bandwidth, $I_0=0.2$ mA is the current used for the noise measurement, $I=0.6$ mA is the current used for the experiment, $S=1.5$ mV/μm is the sensitivity, and Δy is the target resolution.

Taking into account the 30 Hz noise level, the resolution bandwidth and the currents used for the noise measurement and for the experiment, the achievable resolution is 10 nm with a signal to noise ratio of 5.

After a scan is made over the spin valves in order to locate the magnetic element and center it between the two inner spin valves, a second step is carried on. The altitude is decreased in order to reach a higher signal. Contrary to the signal of the center spin valve, the signal of the two outer sensors depends on sample altitude, as shown of Fig. 4(b). The outer sensors are located in the area where the signal changes fast with this distance [the sensitive area for the location of the outer sensors is circled on Fig. 4(a)].

The change of signal during the vertical approach is up to 2 mV/μm. The angular displacement θ causes a variation of altitude of the borders given by $\Delta h=(l/2)\sin(\theta/2)$ with $l=150\ \mu$m. An angular displacement of 0.1° can be measured with a signal to noise ratio of 50 (calculated using the formula above).

In Fig. 5, a scan of the sensitive region is provided, where the movement is done either by step-motors or by piezoelectric actuation. The hysteresis associated with the piezoelectric actuator can be corrected by algorithms.[6]

A static tester was developed; it allows the study of precision actuators, including those which are due to be integrated into future hard disk drives. This tester features two geometries of measurement and is able to show resolution of 0.1 μm laterally and 0.1° of angular resolution.

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#1 Au: Pls. supply full authors' list on Refs. 4-8.
#2 Au: Pls. update Ref. 4 if possible.