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OPTIMIZATION OF MICROELECTRONIC MAGNETIC SENSORS ON THE SPLITTED HALL STRUCTURES

ABSTRACT *The work gives an analysis of the field characteristics of magnetic sensors on the splitted Hall structures. Having a number of advantages (including the capability to be integrated into three-component magnetic probes with high spatial resolution), such splitted Hall structures require further analysis of output voltage dependence on magnetic induction vector. New field characteristic equations are proposed.*

Keywords: *splitted Hall structure, calibration, field characteristic*

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1. INTRODUCTION

One of the structural modifications of Hall devices is an angular splitted Hall structure notable for the fact that its sensitive region is placed in the corner of the substrate as shown in Figure 1b [1-4]. Placing three such splitted Hall structures on the adjacent edges of the cubic substrate, one would obtain a high-resolution 3D magnetic sensor with the following additional advantages: opportunity of direct contact between the cube corner and measured surface; high magnetic sensitivity (100÷300 mV/T), low parasitic cross-sensitivity (< 1%); opportunity to work in harsh environment including cyclotrons and charged particle accelerators.

However, the structural features of the splitted Hall structures not only cause their advantages, but also complicate the process of their calibration.

2. SPLITTED HALL STRUCTURE FIELD CHARACTERISTIC

The field characteristic of any ordinary Hall device fed by constant current can be described by linear equation or, more accurately, by second-degree polynomial. These equations take into account only the magnetic-field vector component B_N normal to the sensor plane, but neglect two magnetic-field vector projections lying in the sensor plane, one of which, B_L, is parallel and the other, B_W, is perpendicular to the current line [1, 2]. The field characteristic was assumed to be a second-degree polynomial when calibrating 3D sensors based on three orthogonally turned splitted Hall structures. The results were correct in magnetic fields up to 300 mT (with inaccuracy not exceeding 0.3%) but in a magnetic field 1 T the inaccuracy ran up to several percents. So we concluded that a profound analysis of the output voltage dependency on the magnetic-field vector $\vec{B}$ is needed.

Let's represent a splitted Hall structure as an equivalent circuit shown in Figure 1. The resistors R_{11}, R_{12}, R_{13}, R_{21}, R_{22}, R_{23}, R_S stand for the respective parts of the semiconductor layer whilst the voltage sources E_{1H}, E_{2H} substitute for Hall potentials of half Hall elements HHS$_1$, HHS$_2$. The splitted Hall structure feed current leaves the node $\boxed{I_S}$ and enters the nodes $\boxed{I_1}$ and $\boxed{I_2}$. The outputs $\boxed{I_1}$ and $\boxed{I_2}$ are to be joined in order to equalize the currents I_1 and I_2 and consequently the common-mode voltages, taking into consideration that the structure is symmetrical to a first approximation ($R_{11} = R_{21}$, $R_{12} = R_{22}$, $R_{13} = R_{23}$).

However, Hall voltage sources have opposite polarity due to the fact that the potential electrode in HHS_1 and HHS_2 reside on different sides of the current circuit. Consequently we can assume to a first approximation that the differential output voltage $V_{OUT} = V_2 - V_1$ can be represented as $V_{OUT} = V(E_{1H}) - V(E_{2H})$.

However further analysis shows that in the absence of the symmetry of half Hall elements HHS_1 and HHS_2 the output voltage of the sensor depends on change in redistribution of the currents I_1, I_2. The asymmetry can be caused by such factors: 1) imperfection of thin-film structure geometry resulting from photolithographic mesa structure forming; 2) distinct change in resistance of two half Hall elements resulting from magnetoresistive effect.

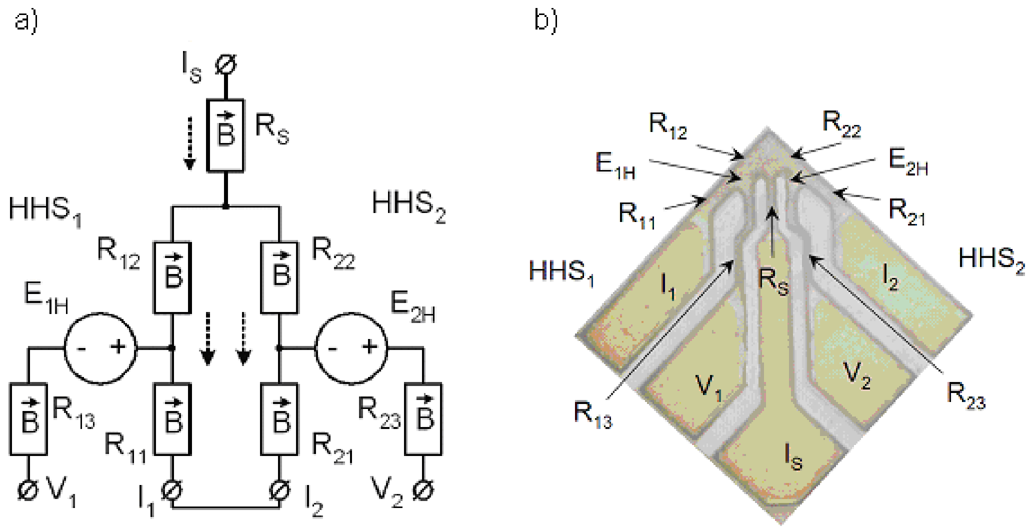

Fig. 1. Splitted Hall structure equivalent circuit (a) and its photo with model elements signed (b)

We have carried out numerous experiments in order to determine the structure resistance change dependence on the magnetic-field vector direction. Three cases were studied when magnetic-field vector: 1) is parallel to the current line; 2) is perpendicular to the current line but parallel to the sensor plane; 3) is perpendicular to the sensor plane and consequently the current line. Upon the obtained results it can be concluded that the most change in structure resistance occurs in the case that the magnetic-field vector is perpendicular to the current-line and parallel to the sensor plane. Upon performed analysis of parasitic voltage dependence on the magnetic-field vector direction we derived the following equations of the field characteristics of the splitted Hall structures in a 3D sensor:

$$V_{OUT1} = V_{01} + K_{B11}B_{N1} + K_{B21}B_{N1}^2 + K_{B31}B_{W1}^2,$$
$$V_{OUT2} = V_{02} + K_{B12}B_{N2} + K_{B22}B_{N2}^2 + K_{B32}B_{W2}^2, \quad (1)$$
$$V_{OUT3} = V_{03} + K_{B13}B_{N3} + K_{B23}B_{N3}^2 + K_{B33}B_{W3}^2,$$

where V_{OUT1}, V_{OUT2}, V_{OUT3} are output voltages of each splitted Hall structure; V_{01}, V_{02}, V_{03} are respective offset voltages; K_{B11}, K_{B12}, K_{B13}; K_{B21}, K_{B22}, K_{B23} are linear and square coefficients of output voltage dependencies on magnetic-field vector projections B_{N1}, B_{N2}, B_{N3}; K_{B31}, K_{B32}, K_{B33} are square coefficients of magnetoresistive modulation that determine output voltages projections on magnetic-field vector projections B_{W1}, B_{W2}, B_{W3} respectively.

3. RESULTS

In order to test the field characteristics (1) for efficiency we compared results of measuring the scalar of the magnetic-field vector $B = \sqrt{B_X^2 + B_Y^2 + B_Y^2}$ when rotating a sensor in a uniform magnetic field randomly. It is obvious that correct calibration causes instability to vanish. Figure 2 shows the results of experiments conducted in magnetic fields of $1\,T$. It can be seen that when

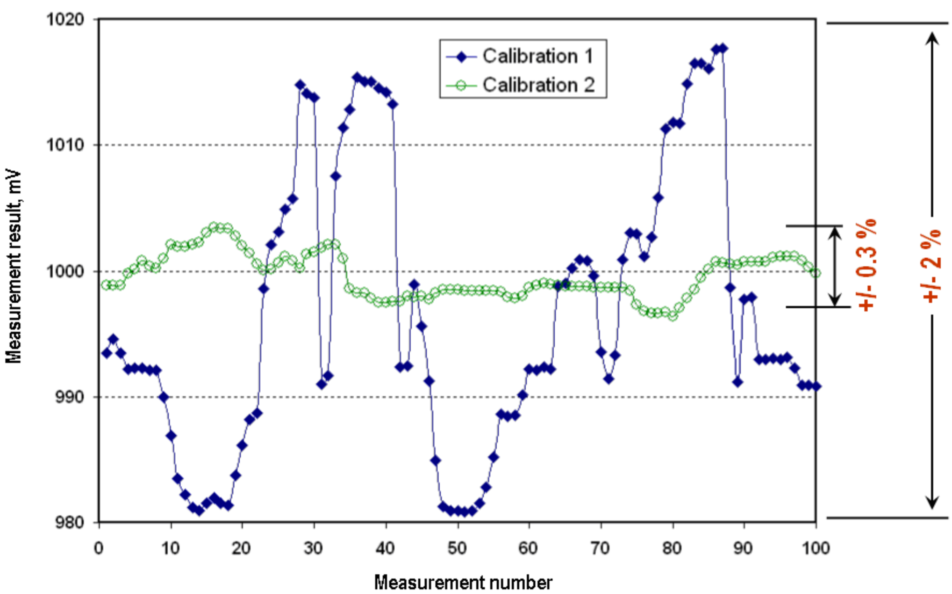

Fig. 2. Results of measuring the scalar of the magnetic-field vector when rotating a 3D sensor in a magnetic field in a random way taking into account the magnetoresistive modulation (Calibration 1) and ignoring it (Calibration 2)

ignoring the magnetoresistive modulation the instability of magnetic field measurement results runs to ± 2% (Calibration 1 plot). When taking into account the magnetoresistive modulation the above-mentioned instability reduces to ± 0.3% which is almost by order of magnitude less (Calibration 2 plot).

4. SUMMARY

The field characteristic equations of magnetic sensors on splitted Hall structures are introduced. Due to these new equations the inaccuracy of calibration of such sensors in a magnetic field of 1 T reduces from 2% to ± 0.3%.

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OPTYMALIZACJA MIKROELEKTRONICZNYCH SENSORÓW MAGNETYCZNYCH NA DZIELONYCH STRUKTURACH HALL'A

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STRESZCZENIE: *Praca przedstawia analizę charakterystyki pola sensorów magnetycznych rozmieszczonych na dzielonych strukturach Hall'a. Dzielone struktury Hall'a mogą być integrowane w trójkomponentowe czujniki z wysoką rozdzielczością przestrzenną. Dzielone struktury Hall'a wymagają dalszych badań dotyczących zależności napięcia wyjściowego od wektora indukcji magnetycznej. W pracy zaproponowano nowe równania charakterystyki pola.*

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