Temperature Influence on Hall Effect Sensors Characteristics

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***Abstract* — Horizontal Hall microsensors, comprising a silicon substrate and four contacts, providing two supply inputs and two differential outputs, are designed and characterized. This paper presents the temperature influence on the residual offset and also on the voltage related sensitivities. The measured voltage related sensitivity is 152 mV/VT. The sensors are tested at 125°C, 85°C, 50°C, 25°C, 0°C, -20°C and -40°C. An offset compensation method is used in order to achieve residual offset in the micro scale (the highest achieved value offset is 6.97 μV).**

***Keywords* — 0.18μm CMOS technology, Hall microsensors, offset, sensitivities, temperature dependence.**

I. Introduction

IN more than a hundred years of their history, Hall effect devices have been used to demonstrate the basic laws of physics, to study details of carrier transport in solids, to detect the presence of a magnet and as measuring devices for magnetic fields. The Hall voltage of a Hall plate can be regarded as signal carrying information. The Hall voltage can give us information about the magnetic induction if we know the material properties, device geometry and biasing condition. Alternatively, we may control the biasing conditions and magnetic induction of a Hall device with a known geometry. From the measured Hall voltage, some important properties of the material the device is made of may be deduced. So, the Hall device can be applied as a means of characterizing material or either as magnetic sensors or as material analysis tools.

The sensors applications of Hall effect devices became important only with the development of semiconductor technology. The development of Hall effect sensors has taken advantage of using high quality materials and sophisticated, highly productive fabrication methods available in the microelectronics industry. Today, the Hall effect microsensors are mostly used as key elements in contactless sensors for linear position, angular position, velocity, rotation, electrical current, and so on. Most currently produced Hall magnetic sensors are discrete elements, but an ever-increasing portion comes in the form of integrated circuits. Integrated Hall magnetic sensors incorporate electronic circuits for biasing, offset reduction, compensation of temperature effects, signal amplification, and more [1].

The key characteristics of Hall effect sensors are the offset and sensitivity and their influence of the temperature. Different methods for offset compensation are known, as improvement of the manufacturing technologies, device symmetry, calibration, mutual compensation, trimming, spinning current offset reduction, etc [2]. The magnetic sensitivity or the transduction efficiency is the most important figure of merit of the magntosensitive devices and all other types of sensors. This parameter is the ratio of the variation in the output signal to the variation in the external magnetic field at a constant temperature, pressure, radiation, etc. It determines the conversion efficiency of the input quantity (the magnetic field ***B***) into electric output signal. The options for enhancing sensitivity S are: 1) optimization of geometrical sizes of the Hall structures so that the geometrical factor G has maximum limit value, $G \approx 1$; 2) using semiconducting materials as *n*-GaAs, *n*-InSb, *n*-Si, etc. with low value of the electron concentration in the Hall plate substrate n (accordingly, with high carrier mobility μ) or 3) small thickness t of the sensor [3]. Our previous research comprises the design and investigation of horizontal Hall sensors, using different technological methods for offset compensation at constant temperature, in order to achieve higher output signal (Hall voltage) and of course as a result to achieve higher sensitivity of the Hall sensors, as it was reported in [4]. The higher achieved residual offset at room temperature is 1.5μV. In this paper it will be reported how the temperature influence to these key characteristics.

II. Sensor's Structure and Operation Principle

A simple geometry plate-like Hall device which is suitable for our further analysis is shown in Figure 1.

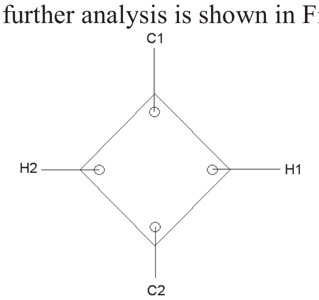

Fig. 1. Hall Plate Structure.

The sample is a thin plate of conducting material (pSi)

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with four electrical contacts at its periphery. A bias current (or voltage) is applied to the device through two of the contacts, called the current contacts (C_1 and C_2). The other two contacts are placed at two equipotential points at the plate boundary and are called the voltage contacts or the sense contacts. If a magnetic field is applied to the device, a voltage appears between the sense contacts, which is called the Hall voltage.

The Hall device is with the form of square plate and is with microscopic dimensions (40 x 40μm). A bias voltage V is applied to the plate through the two current contacts C_1 and C_2. The bias voltage creates an electric field E and forces a current I. If the plate is exposed to a perpendicular magnetic induction $\boldsymbol{B}$, the Hall electric field E_H occurs in the plate. The Hall electric field gives rise to the appearance of the Hall voltage V_H between the two sense contacts H_1 and H_2. The designed and investigated sensor's layout is illustrated on Fig. 2.

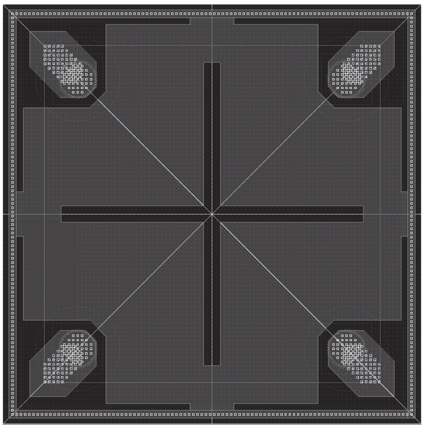

Fig. 2. Hall Plate Layout.

The Hall microsensors were manufactured in a standard planar technology on p-Si wafers, with substrate resistivity 0,01 Ωcm and crystallographic direction (100). The heavy doped n+ and p+ regions are with depth of 35nm and STI (shallow trench isolation, which is used) depth is 400nm. The microdevices are confined in N-well, which serves as an active sensor zone with depth of 1.5μm. Fig. 3 illustrates the measurement principle.

The measurements involve applying a voltage (from 0.5V to 3.0V with step 0.5V) and measuring a voltage (Hall voltage). The idea of the measurement principle is first to rotate the polarity of the supply voltage and the polarity of the Hall voltage (output signal), and than we reconnect the relevant contact pairs, whereas the bias contacts become output contacts, and the supply contacts are used as sense terminals. In every rotation of the contacts we again rotate the polarity of the input and output signal.

Due to the fact that the Hall structure is symmetric with rotation, this technique leaves the output Hall voltage V_H unchanged in value and sign. During the terminals' rotation, this results in polarity reversion of the offset voltage.

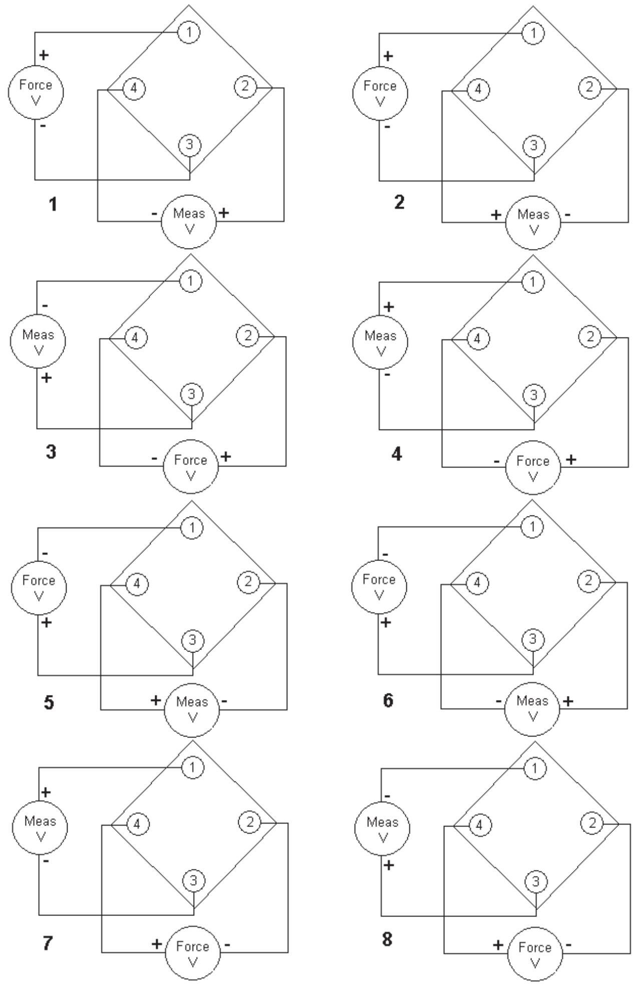

Fig. 3. Measurement principle.

The net effect is "to see" the Hall signal as rotating in the same direction as the bias voltage and current, while the ohmic offset rotates in the opposite direction [5]. So, as a result, the residual offset is almost compensated and there is no need to use an offset compensation circuits using this technique. The output voltage for semiconductors is typically about mV.

III. Experimental Results

The investigated Hall sensors were designed on 0.18μm CMOS technology. A four-phase spinning method is used for offset compensation, which involves a combination of reversing source voltage polarity and also reversing the input and output terminals. In order all measurements to be performed, the test equipment shown on Fig. 4 was prepared. Four Hall plates can be tested at once with the prepared equipment. It is composed of one switch matrix board with 64 relays which switch the Hall plates' diagonals for offset compensation. Also for chip measurements a Keithley 2602 was used, which is duo channel source meter with 10000 readings/s and 5500 source-measure points/s to memory. The first channel is used to supply the sensors and the second one is used to measure the output signal. The KEPCO drives the current through the coil and this way the magnetic field is generated. The desired temperature is achieved using a thermostreamer.

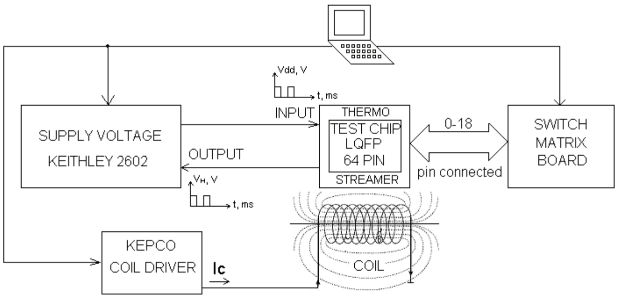

Fig. 4. Block diagram of the test process.

The plates are tested with six supply voltages (0.5V, 1.0V, 1.5V, 2.0V, 2.5V, 3.0V). A LabVIEW program was created in order more automated test process to be achieved. Its functions are to drive the Keithley instrument and the switch matrix board, so consecutively to supply and measure all diagonals of the tested four Hall structures.

The first important parameter which was investigated is the residual offset, calculated after the four-spinning phase compensation method was applied, in order the offset value to be decreased in the micro scale. Before the compensation method to be calculated, the offset of the sensor at 25°C is 1.23 mV. For comparison, a similar product that is already in the market has been reported to have static offset min/max value 10mV [6]. In Table 1 the calculated values for residual offset in µV are given. The measurements are taken for eight different temperatures (125°C, 85°C, 50°C, 25°C, 0°C, -20°C, -40°C). Fig. 5 illustrates the residual offset as a function of the supply voltage.

TABLE 1: RESIDUAL OFFSET [µV].

T, [°C]	*Supply Voltage [V]*					
	0.5	***1.0***	***1.5***	***2.0***	***2.5***	***3.V***
125	-0.25	0.92	0.89	2.31	2.31	5.29
100	-1.89	-0.31	-0.42	1.25	2.75	2.76
85	-0.26	-0.61	1.82	2.73	2.51	3.97
50	-1.17	-1.91	-0.89	1.04	0.67	2.25
25	-1.63	-0.86	-1.19	-1.64	-1.42	-0.92
0	-2.38	-2.94	-2.64	-3.81	-4.79	-3.93
-20	-2.33	-3.35	-4.00	-4.36	-4.17	-6.36
-40	-3.50	-5.51	-5.52	-6.02	-5.52	-6.97

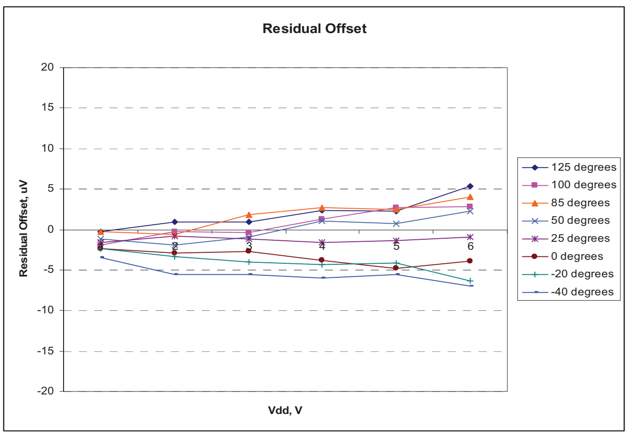

Fig. 5. Residual offset as a function of the temperature.

The measurements are taken and averaged for few samples. It is clearly visible that as lower the temperature is, as higher the offset value is. The worst offset results are at -20ºC and -40ºC which can be explained with the fact that when the temperature is lower the potential between the contacts becomes higher. Nevertheless, these values are not out of specifications and will not affect the sensors' characteristics.

Next, the Hall voltage is investigated also at eight temperatures. In Table 2 and 3 the values for Hall voltage are presented, at magnetic field ***B*** = 8mT and ***B***=-8mT respectively.

TABLE 2: HALL EFFECT VOLTAGE [mV] AT B = 8MT.

T, [°C]	*Supply Voltage [V]*					
	0.5	***1.0***	***1.5***	***2.0***	***2.5***	***3.V***
125	-0.30	-0.60	-0.90	-1.20	-1.50	-1.80
100	-0.33	-0.66	-0.99	-1.32	-1.65	-1.98
85	-0.35	-0.69	-1.04	-1.39	-1.74	-2.08
50	-0.40	-0.80	-1.20	-1.60	-2.00	-2.39
25	-0.45	-0.90	-1.35	-1.79	-2.24	-2.68
0	-0.50	-0.99	-1.48	-1.98	-2.47	-2.95
-20	-0.55	-1.10	-1.64	-2.18	-2.71	-3.25
-40	-0.60	-1.21	-1.81	-2.40	-2.99	-3.58

TABLE 3: HALL EFFECT VOLTAGE [mV] AT B = -8MT.

T, [°C]	*Supply Voltage [V]*					
	0.5	***1.0***	***1.5***	***2.0***	***2.5***	***3.V***
125	0.30	0.60	0.90	1.20	1.50	1.80
100	0.33	0.66	1.00	1.33	1.66	1.99
85	0.35	0.70	1.05	1.40	1.75	2.10
50	0.40	0.80	1.20	1.61	2.01	2.41
25	0.45	0.90	1.35	1.80	2.25	2.69
0	0.50	1.00	1.50	2.00	2.50	2.99
-20	0.55	1.10	1.64	2.19	2.73	3.27
-40	0.61	1.23	1.84	2.45	3.06	3.66

Next measurements concern the investigation of the Hall voltage as a function of the applied voltage supply and the applied magnetic field.

In Fig. 6 the Hall voltage as a function of the temperature at magnetic field ***B*** = 8mT and ***B***=-8mT is shown.

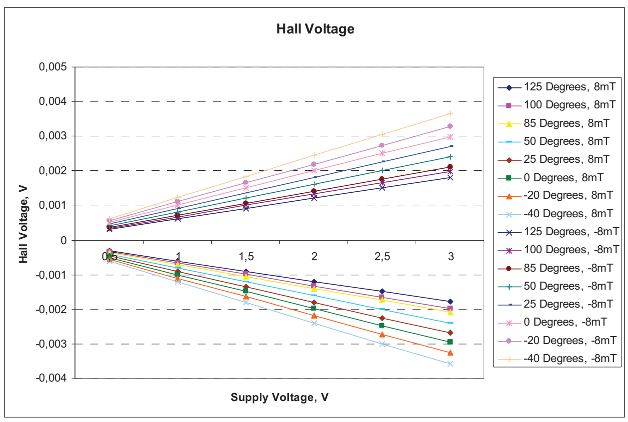

Fig. 6. Hall voltage as a function of the temperature.

The magnetic field is applied perpendicular to the Hall plate's surface. The higher measured value for the Hall voltage is $V_H = 3.66$ mV at -40 °C. It is clearly visible that as lower the temperature is, as higher the output signal is. This is due to the fact that when the temperature is lower (-40 °C), at voltage biasing, the resistance of the Hall plate is smaller, so the current through the plate is higher, and as a consequence the Hall voltage becomes higher. Also the oscillations in the crystal lattice are lower and the carriers' mobility is higher.

Next, voltage related sensitivity is measured and investigated. The values calculated for the voltage related sensitivity for the eight temperatures are shown in Table 4.

TABLE 4: VOLTAGE RELATED SENSITIVITY [mV/VT] AT B = 8MT.

T, [°C]	***Supply Voltage [V]***					
	0.5	***1.0***	***1.5***	***2.0***	***2.5***	***3.V***
125	75.48	75.12	75.11	74.95	74.66	74.67
100	83.40	83.14	82.87	82.89	82.65	82.55
85	87.68	87.48	87.38	87.24	87.11	86.91
50	101.2	100.6	100.5	100.4	100.2	99.90
25	112.9	112.9	112.6	112.3	112.1	111.9
0	125.2	124.7	124.0	124.0	123.6	123.2
-20	137.3	137.0	136.7	136.3	135.9	135.4
-40	151.8	151.7	150.9	150.5	149.9	149.3

The voltage related sensitivity is calculated using (1):

$$S_V = \frac{V_H}{V_{DD} B}, T^{-1}. \qquad (1)$$

S_V is the voltage related sensitivity, V_H is the Hall voltage, V_{DD} is the supply voltage and ***B*** is the applied magnetic field. Fig. 7 illustrates the results.

The maximum achieved sensitivity is 0.15 T^{-1} at -40 °C where the output signal is higher. The stability of the sensors' voltage related sensitivity as a function of the increasing supply voltage is clearly visible from Fig. 8. The lowest achieved sensitivity is at 125 °C and it is 0.075 T^{-1}. As a comparison, a typical value for voltage related sensitivity in the literature is 0.05 to 0.08 T^{-1}. We obtained really high voltage related sensitivity which is a key characteristic for such type magnetic devices

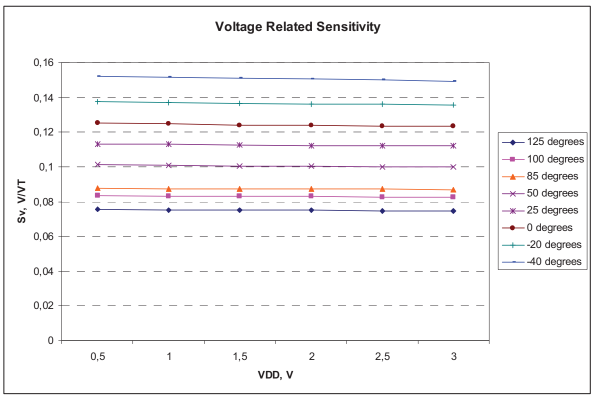

Fig. 7. Hall voltage as a function of the supply voltage.

Our next investigation concerns the dependence of the voltage related sensitivity of the temperature. Fig. 8 illustrates this dependence.

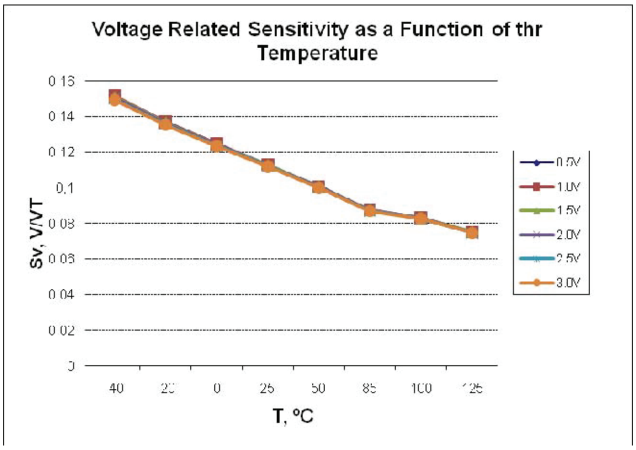

Fig. 8. Hall voltage as a function of the temperature.

The lower the temperature is, the higher the voltage related sensitivity is. The output signal is higher, because of the higher mobility of the carriers and as a consequence the sensitivity becomes higher.

IV. CONCLUSION

This paper has reported the design, operation and characterization of horizontal silicon Hall microsensors and the temperature dependence of its parameters. The Hall devices for magnetic field, giving a high Hall voltage with low residual offset and high sensitive signal are presented and tested. The Hall elements are ready for a wide range of practical applications, as metrology, automotive industry, telecommunications, robotics, remote sensing, etc. The designed 0.18µm CMOS integrated circuit Hall sensor, with proved advantages can successfully compete with other horizontal microdevices.

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