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Evaluation of characteristic parameters for high performance hall cells

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ABSTRACT

The current work focuses on presenting specific Hall cells with high performance, and their corresponding parameters. The design, integration, measurements and model development for their performance assessment are necessary stages considered in the generation of the Hall cells. Experimental results regarding the Hall cells absolute sensitivity, offset and offset temperature drift are provided for two particular structures exhibiting the best behavior in terms of maximum sensitivity and lowest offset. Three-dimensional physical simulations were performed for the structures and the Hall mobility was extracted. Representation of the inverse of the geometrical correction factor for the Greek-cross Hall cell is also provided.

1. Introduction

The Hall Effect sensors are used in many applications, for example in the DC brushless motor, for the contactless measurements of mechanical quantities like position or angle. They are also used for direct magnetic field sensing, as in electronic compasses. Silicon Hall sensors are often prime candidates for such applications due to their cost-effective integration potential, reflected in low cost, robustness and versatility [1].

CMOS technology has also the advantage of easy co-integration with electronics on the same chip. The Hall Effect is based on magnetic field influence acting perpendicularly on a semiconducting structure carrying a certain electric current. Due to the fact that the charge carriers moving in a magnetic field are subject to a Lorentz force, a so-called Hall voltage is induced in the device in a direction perpendicular to the current flow. New research is devoted to submicron Hall Effect sensors which are nowadays used for the detection of the supermagnetic beads [2].

As it is known, the principal accuracy limitations that affect Hall Effect sensors performances are the offset and its temperature drift [3]. Potential sources of offset generation are related to the fabrication process of a Hall cell, packaging, operating conditions and ageing [4]. The major source for the offset voltages apparition is the imbalances of the Hall plate. Therefore, a real Hall sensor could have a zero-field offset due to possible geometrical mismatches. In order to eliminate the offset of Hall sensors, the dynamic method known as "current-spinning technique" is used [5–8]. An important figure of merit of these sensors is the sensitivity which is strongly limited by the short-circuit effects. A high absolute sensitivity improves the signal-to-noise ratio of magnetic sensors [9].

Compact models of cross-shaped Hall sensors have recently been developed [10]. The performance of the horizontal Hall sensors in CMOS technology has been greatly improved over the last years. Hall devices with offset less than 10 μV [11] and integrated Hall sensors with an offset drift lower than 1.5 μT/°C [12] were reported.

Extensive analysis of the geometry influence on the Hall cells performance was presented in various recent papers by the authors, which also provided three-dimensional simulations for their assessment and proposed a large experimental database for the parameters that govern their behavior, especially the offset [13–17].

The work in this paper aims at presenting two different Hall cells which can be used for high performance achievement. The proposed structures were integrated in a 0.35 μm CMOS technology and thoroughly tested amongst others for sensitivity, offset and offset drift. The objectives were to select Hall cells able to provide a low offset (below 30 μT) at the room temperature and a low offset temperature drift (less than 0.3 μT/°C), a few times lower than the state-of-the-art.

Section 2 is devoted to Hall cells geometrical considerations and Hall cells design parameters. Section 3 incorporates the experimental results obtained for two particular Hall cells, regarding offset voltages, magnetic equivalent residual offset at room

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temperature versus the biasing current and its temperature drift. Section 4 focuses on the results obtained by the three-dimensional simulations used to predict the Hall cells performance. At this point, the Hall mobility is extracted and commented. Finally, the paper concludes with the emphasis on the two proposed Hall cells selected for minimum offset and offset drift and high absolute sensitivity respectively.

2. Hall cells geometrical considerations

2.1. Hall voltage and sensitivity

Any Hall Effect device is characterized by the Hall voltage V_{HALL}, given as follows:

$$V_{HALL} = \frac{Gr_H}{nqt} I_{bias} B \tag{1}$$

where B is the magnetic field induction, G is the geometrical correction factor, I_{bias} is the biasing current, r_H is the Hall scattering factor, n is the carrier density and t is the thickness of the active region [18]. In the case of silicon, the Hall scattering factor is usually 1.15.

The geometrical correction factor, G, models the reduction of V_{HALL} due to the part of the current which flows through the sensing contacts. It is worthwhile mentioning that there are different symmetrical shapes for the Hall cells, such as plate, cross, square and other. The geometrical correction factor G tries to answer to the geometry variance and Hall voltage modification for a cell having a certain shape.

Sensitivity is one of the most important figures of merit related to a sensor. In general, the sensitivity is defined as the change in output resulting from a given change in input. Consequently, both absolute and relative sensitivities can be introduced. All the equations below are introduced exactly as in Popovic's book [18]. Firstly, the absolute sensitivity of a Hall magnetic sensor is considered as given by the equation below:

$$S_A = \left| \frac{V_{HALL}}{B} \right| = \frac{Gr_H}{nqt} I_{bias} \tag{2}$$

The ratio between the absolute sensitivity and a certain bias quantity accounts for bias-related sensitivity. Secondly, the current-related sensitivity S_I has the following relation:

$$S_I = \frac{S_A}{I_{bias}} = \left| \frac{1}{I_{bias}} \frac{V_{HALL}}{B} \right| \text{and} V_{HALL} = S_I I_{bias} B \tag{3}$$

The units of S_I are $\mathrm{VA}^{-1}\,\mathrm{T}^{-1}$.

2.2. Geometrical correction factor

In the literature, the expression of the geometrical correction factor G has been obtained by conformal mapping, for various shapes of Hall cells. The formulae, different for each configuration, are valid under some accuracy limitations and only work for certain relationships between the geometrical parameters (length, width, contacts length, etc.) of the corresponding cell.

In this paper, we were interested to analyze the Greek cross shape. For the classical Greek-cross with contacts on each side, the expression of the geometrical correction factor G [19] is given by the following expression:

$$G = 1 - 7.896\ \mathrm{m}\ \mathrm{cotan}(\theta_H) \exp\left(\frac{-\pi}{2\lambda} \right),\ \lambda \to 0 \tag{4}$$

The equation above is valid for λ approaching 0, where the parameter λ denotes the ratio of the sum of the lengths of the contacts c and the length of the boundary b.

$$\lambda = \frac{c}{b} \tag{5}$$

Further on, m is defined through the Hall angle θ_H with the aid of the formula:

$$\theta_H = \frac{m\pi}{2} = \arctan(\mu B) \tag{6}$$

By consequence, m is defined as follows:

$$m = \frac{2\theta_H}{\pi} \tag{7}$$

It is to be mentioned that there are other equivalent formulae for the geometrical correction factor G for the Greek-cross cell which use the relations in the length and width of the cell (L and W, respectively). More details about the Hall cells geometrical parameters can be found in [13,14].

The importance of the geometry in high sensitivity achievement was investigated by the authors in previous papers [13,20]. To this purpose, maximization of the geometrical correction factor for structures with small sensing contacts was performed. A high sensitivity can be achieved in a Greek-cross structure with large contacts and high L/W, but also in a rectangular Hall structure with very small sensing contacts.

For the Greek cross case, the three-dimensional representation of the inverse of the geometrical correction factor G versus m and λ is represented in Fig. 1.

2.3. Hall cells design

A dozen of different Hall cells were integrated in a 0.35 μm CMOS technology, in two silicon runs. We will focus in this paper on only two of them, XL and square Hall cells respectively.

The *XL* Hall cell is a scaled version of a basic Greek cross cell. This configuration was chosen in order to minimize the errors of the contour which become less important in this case, due to their averaging on a greater size. This assumption is confirmed experimentally as well. The *square* cell has very small sensing contacts for high absolute sensitivity achievement, but the location of the contacts on the p-n junction and the small size of this cell could possibly increase the offset.

This section presents the Hall cells specific design considerations and summarizes the geometrical parameters for two of the integrated Hall cells, displaying the highest sensitivity (square) and both the lowest offset and temperature drift (XL) respectively. Detailed offset measurements results are presented in Section 3.

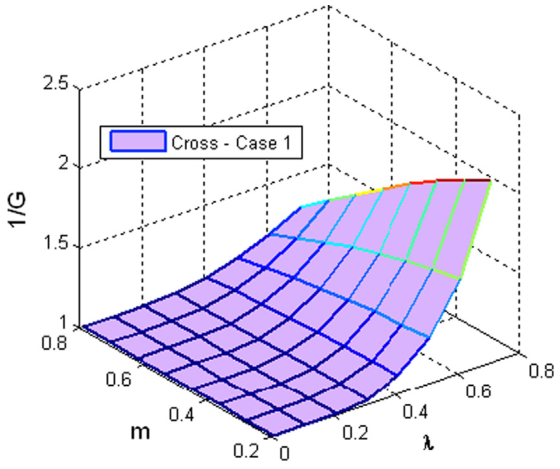

Fig. 1. $1/G$ versus m and λ, for cross Hall structures.