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Ultra-Low Offset Vertical Hall Sensor in CMOS Technology

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Abstract

This paper reports on a novel vertical Hall sensor with ultra-low offset (ULOVHS) for the measurement of an in-plane magnetic field component. The sensor consists of four parallel coupled fully symmetric vertical Hall sensors (FSVHS). Each FSVHS is formed by the connection of four identical three-contact vertical Hall elements (3CVHE). As a result, with a bias current of 0.5 mA and after current switching, a mean residual offset of 0.27 μV with a standard deviation of 0.29 μV has been achieved among 40 samples on an 8-inch wafer, which is an improvement of a factor of 16 compared to the FSVHS (4.2 \pm 14 μV). Furthermore, the measured current related sensitivity of the novel device is $S_I = 12.65 \text{ V/AT}$, allowing the detection of magnetic fields down to $B_{\min} = 40 \mu\text{T}$ without any additional electrical compensation circuitry. This represents the best results to date achieved by a stand-alone VHS in standard CMOS technology.

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1. Introduction

Among the various sensing methods to detect magnetic fields, the Hall-effect is probably the most widely used. A promising approach for implementing low-cost three dimensional (3D) magnetometers is the combination of Hall plates with vertical Hall sensors (VHS) using standard integrated circuit (IC) processes. Thereby, planar Hall plates are sensitive to the magnetic field component perpendicular to the chip surface, while VHS transduce the magnetic field in the plane of the chip [1,2]. In general, the output voltage of Hall-effect devices can be written as

$$V_{\text{out}}(B) = V_{\text{Hall}}(B) + V_{\text{off}} = S_V V_{\text{in}} B + V_{\text{off}} \quad (1)$$

where $S_V = V_{\text{in}}^{-1} dV_{\text{out}} / dB$, V_{Hall} , V_{in} and $V_{\text{off}} = V_{\text{out}}(0)$ denote the voltage related sensitivity, the Hall voltage, the bias voltage and the offset of the device in the absence of a magnetic field, respectively.

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Whereas planar Hall plates show a respectable offset performance, conventional vertical Hall sensors (VHS) are subjected to higher offsets at, generally, lower sensitivities. Further, offset compensation techniques like hard-wiring [3] and current spinning [4] are less efficient. State-of-the-art VHS with four, five or six contacts suffer from either large initial offsets or high residual offsets after current spinning [5]. In both cases a pre- or post-compensation of the sensor offset is necessary, which increases the chip area for signal conditioning circuitry and the packaging cost.

Recently, we proposed the first fully symmetric vertical Hall sensor (FSVHS) with an electrical symmetry equivalent to planar Hall devices [6]. The inherent symmetry of the FSVHS results in an equivalent magnetic offset field in the range of a few hundreds of μT . However, for highly precise applications a calibration of the offset voltage of each sensor is still necessary. The rationale of this paper is the expectation that the conventional parallel coupling of FSVHS is able to improve the electrical symmetry of the device and its offset characteristic even further.

In this work, we present a novel ultra-low offset VHS (ULOVHS) with a residual magnetic offset field of tens of μT . In Section 2, the concept and the CMOS design are introduced. The experimental examination of the offset, sensitivity and noise characteristic of the novel device and corresponding FSVHS are described in Section 3.

2. Device Structure

In [7] it has been concluded that the ideal VHS is a four-contact device benefiting from equivalent current flow distributions in all operating modes. The FSVHS is the first device to meet those demands [6]. As shown in Fig. 1(a), it consists of four three-contact vertical Hall elements (3CVHE) connected by metal lines of identical resistance. The center contacts C1 to C4 serve for biasing and sensing, enabling the device to be operated in four different modes [see Fig. 1(b)]. However, the symmetry of the device is affected by resistive mismatches introduced by the fabrication process. Due to the strong suppression of non-linear effects caused by the junction field effect (JFE), residual offsets in the range of tens of μV are the result. Besides current-spinning, hard wiring, or orthogonally coupling of two or more identical Hall sensor is known to effectively reduce the offset. Thereby, parallel coupling suppresses the influence of systematic fabrication errors. Current-spinning combined with orthogonal coupling have resulted in residual offset fields down to several μT for state-of-the-art planar Hall plates [8].

The new ULOVHS consists of four parallel FSVHS coupled as schematically shown in Fig. 2(a). Each FSVHS and thus the entire ULOVHS are composed of 3CVHE. The schematic cross-section and a photograph of the 3CVHE realized in sub-micron CMOS technology are shown in Figs. 2(b) and (c). It consists of a deep n-well diffused into a p-doped substrate. Its three n^+ -diffusions serve to interconnect the elements and operate the device.

3. Experimental Results

The offset characterization of the ULOVHS and corresponding FSVHS were performed at the wafer level using the semi-automatic wafer prober PA200 from Süss combined with the parameter analyzer B1500 from Agilent. For this measurement the bias current I_{in} is swept between 0 and 1 mA and V_{off} is extracted for each mode of operation. The typical offset voltage of an ULOVHS is illustrated in Fig. 3. All modes show a dominantly linear behavior. Due

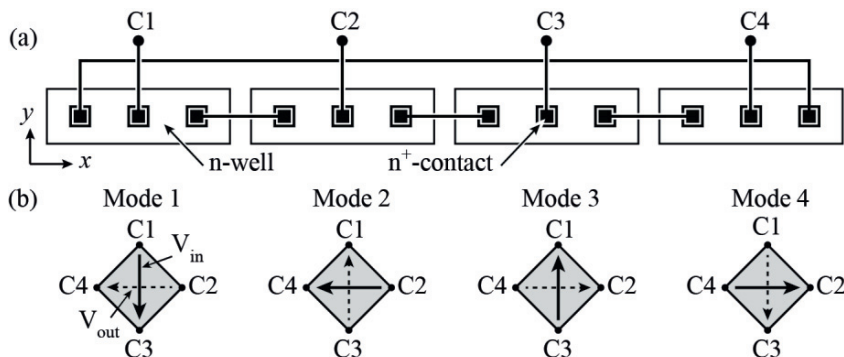


Figure 1. Schematic of (a) a FSVHS and (b) its four modes of operation.

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