First Vertical Hall Device in standard 0.35 μm CMOS technology

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In order to lower the short-circuit effect due to the measurement contacts, Vertical Hall Devices (VHDs) are generally designed either in bulky N-type silicon or in the deep N-well of high-voltage CMOS technologies. In this last case, VHD can benefit from on chip circuitry for offset and 1/f noise reduction, but HVC莫斯 remains a costly technology. Using spinning-current, HVCmos compatible VHDs with a resolution of 76 μT rms over a 1.6-kHz bandwidth have been demonstrated. The VHD presented here is designed in the shallow N-well of a low-cost 0.35 μm standard CMOS technology. Unlike conventional VHD, its measurement contacts are located outside the sensor active area. FEM simulations and experimental results show that the new geometry suppresses the short-circuit effect and strongly reduces the intrinsic offset and noise. Thus, without any noise and offset reduction method, this new small VHD (63 μm²) reaches a resolution of 79 μT rms over a (5 Hz–1.6 kHz) bandwidth, and opens the way to the integration of 3D Hall sensors in low-cost standard CMOS technologies.

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1. Introduction

The Vertical Hall Device (VHD), which is sensitive to a magnetic field in the plane of the chip, was devised more than 20 years ago [1,2]. Such a device is also named parallel-field Hall microsensor [3–5]. Until now, it has been manufactured as a discrete component [6] because its biasing current has to flow in the depth of the device, preventing its integration since no current can be injected in the substrate of a CMOS circuit. Recently, a VHD designed with device, preventing its integration since no current can be injected doi:10.1016/j.sna.2008.03.01 1 0924-4247/$ – see front matter © 2008 Elsevier B.V. All rights reserved.

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The electric field lines form a constant angle oriented to the plane of the chip. In addition, the current lines and the carrier mobility and the magnetic field orthogonally oriented to the current lines. Therefore, when performing a conformal mapping, which is a geometrical transformation that preserves the angles, we obtain an equivalent plate with a different geometry.

2.2. Conformal mapping and VHD structures

In the previous section, we mentioned that a horizontal Hall effect device is sensitive to the magnetic field orthogonally oriented to the plane of the chip. In addition, the current lines and the electric field lines form a constant angle $\theta_H = \mu_B B$, where $\mu_B$ is the carrier mobility and $B$ the magnetic field component orthogonal to the current lines. Therefore, when performing a conformal mapping, which is a geometrical transformation that preserves the angles, we obtain an equivalent plate with a different geometry.

Fig. 2 illustrates the bilinear transformation which transforms the unit circle in the complex t plane into the upper half plane in the complex z plane. As stated in the previous section, with point-like contacts, the unit circle is equivalent to a traditional Hall plate with a geometrical factor $G = 1$. Assume now that such a circle is placed vertically in the wafer. This structure is not practically feasible in a planar technology since contact $T_1$ would then be located in the depth of the substrate. On the contrary, the equivalent structure in the upper half plane of the complex z plane can be carried out in a CMOS planar process since all the contacts are located on the same side that is the top side of the wafer. Practically, the Vertical Hall Device is implemented in the N-well of the CMOS technology and exhibits finite dimensions. In particular, the VHD depth is limited to roughly 2 μm in a low-cost standard 0.35 μm CMOS process. As a matter of fact, each structure is sensitive to the magnetic field and the biasing and sensing contacts are point like.

In the complex $t$ plane, the Hall voltage is measured between $T_A$ and $T_C$, $V_H = V_{TA} - V_{TC}$ where $T_B$ is the center of the circle (Fig. 2). Due to the central symmetry, the $V_{TB}$ potential does not change whatever the value of the magnetic field applied to the circular device is. On the contrary, for its counterpart in the non-infinitely deep z plane, this is not the case (see Section 2.3), and to measure the same sum of voltages in the z plane, we need an access to the rear side of the N-well, that means to points $Z_0$ and $Z_1$ which are not located at the infinite in the N-well deepness as they should be theoretically. In that configuration, we could have the same Hall voltage as in the $t$ plane $V_H = V_{TA} - V_{TC} = V_{TB}$. Of course, that is not possible in planar technology since we have no access to $Z_0$ and $Z_1$. Hence, measuring the Hall voltage in the z plane does not permit to obtain 100% of the theoretical sensitivity $S_{max}$. It is important to note that even if the VHD is deep enough for the Hall voltage to vanish at the rear side, a Hall voltage will then settle at the lateral sides, whatever the distance between these lateral sides is. In other words, using planar technologies with all the contacts on the same side, the sensitivity measured between two sensing contacts of any VHD will be only a fraction of $S_{max}$. Whatever the relative location of the sensing and biasing contacts is, these contacts being point-like or not.

Fig. 1. Horizontal Hall plate.

obtained as [6]

$$S = \frac{V_H}{B} = \frac{G \cdot r_H}{n \cdot q \cdot t} \cdot I_p = S_I \cdot I_p$$

where $t$ is the plate thickness and $I_p$ the biasing current. $G$ is the geometrical factor ($G < 1$) which models the reduction of $V_H$ due to the part of the current which flows through the sensing contacts $T_A$ and $T_C$ as well as the short-circuit effect induced by the biasing contacts $T_0$ and $T_1$. $S_I$ is the current-related sensitivity. We define $S_{max} = S_I$ when $G = 1$:

$$S_{max} = \frac{r_H}{n \cdot q \cdot t}$$

$S_{max}$ only depends on the plate doping level $n$ and on the thickness $t$. Thus, whatever the plate geometry is, the theoretical maximum sensitivity remains the same as long as $G = 1$. In particular, this is the case if biasing and sensing contacts are point like.

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