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Abstract

A New Hall Microdevice with Minimal Complexity †

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Abstract: A new Hall microdevice with minimal complexity and orthogonal magnetic field activation is suggested. The microsensor contains a rectangular *n*-type silicon substrate. On the long sides, three ohmic contacts are formed symmetrically and opposite each other. The first two opposite electrodes are connected and the second two are fed in the same way, and third ones are the outputs. The increased sensitivity constituting 40 V/AT is due to the reduced parasitic surface currents. Furthermore, output electrodes are moved out of the area where the supply currents flow. The $80 \times 135\ \mu m^2$ size of the sensor increases the resolution and provides detailed mapping of the magnetic field's topology.

Keywords: Hall effect; vertical Hall element; orthogonal Hall configuration; sensor characteristics

1. Introduction

The first three-contact (3C) silicon Hall sensor, activated by the magnetic field ***B*** parallel to the substrate's plane, known also as a vertical or in-plane Hall element, was designed in 1983 by C. Roumenin and P. Kostov. It contains an *n*-Si plate with only three contacts on one of its sides—one central and two symmetrical to it. The end contacts through load resistors are connected to the central electrode via a supply source. Moreover, they constitute the output. The disadvantage of this single-ended microsensor is the decreased sensitivity resulting from the parasitic surface currents flowing between the contacts. Technological implementation is complicated because of the different-in-their-essence formation processes of the ohmic electrodes and load resistors. Vertical Hall elements represent a promising approach for implementing fully integrated 3D vector probes, as they have a multitude of applications in which the orthogonal activation by field ***B*** is preferred. This paper presents a transformation of a vertical Hall element into an orthogonal sensor configuration with minimal design complexity and a promising performance.

2. Device Structure and Operation

In Figure 1, the top view of the new Hall microdevice is shown. On the long sides of the thin *n*-Si substrate, two groups of three heavily doped n^+ ohmic contacts, namely C_1, C_2, and C_3 and C_4, C_5, and C_6, respectively, are formed symmetrically and opposite to each other. The first two opposite electrodes are connected and the second two are fed in the same way; the third ones are the output. A deep surrounding *p*-ring is also present, which reduces the spreading of surface currents and confines the transducer region in the substrate. Contacts C_3 and C_6 of the sensor are those which are moved out of the areas where supply currents $I_{C1,2}$ and $I_{C4,5}$ flow. Field ***B*** is perpendicular to the plane, and electrodes C_3 and C_6 constitute the differential output $V_{HC3,C6}(\boldsymbol{B}) \equiv V_H(\boldsymbol{B})$. The operation is as follows. The supply contacts C_1, C_2, C_4, and C_5 are equipotential surfaces. As a result, the current lines $I_{C1,2}$ and $I_{C4,5}$ are initially perpendicular to them and penetrate deeply into the *x*-*y* area of the substrate. The field ***B*** leads to the Lorentz lateral deflection of the current paths in the *x*-*y* plane. They generate opposite-sign charges in the zones with contacts

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C_3 and C_6, i.e., $V_H(\boldsymbol{B})$. The specific two single Hall devices share the same active region. The elements with contacts C_1, C_2, and C_3 and C_4, C_5, and C_6, respectively, are controlled by the components I_{C2} and I_{C5}. The increased sensitivity of the device results from the drastically reduced parasitic surface currents from the location of contacts C_1 and C_2 and C_4 and C_5 on the various long sides.

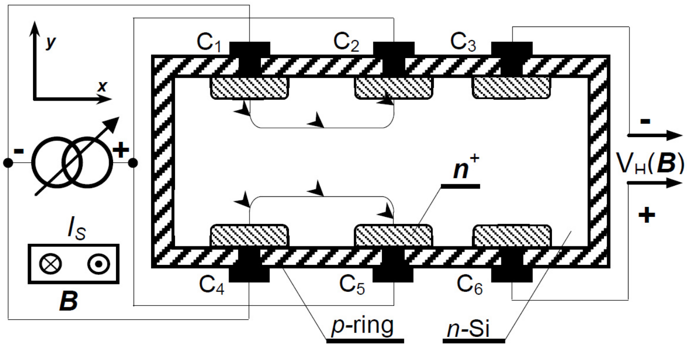

Figure 1. Schematically plan-view of the new Hall configuration. In the *x*-*y* plane, the length of contacts C_1–C_6 is 30 µm, their width is 10 µm, and the depth is about 2 µm. The distance between electrodes C_1, C_2, and C_4 varies: C_5 is 20 µm, while $l_{C2,3}$ and $l_{C5,6}$ are 15 µm (on the mask). The width of the *p*-ring on the chip surface is about 20 µm.

3. Experimental Results and Conclusions

The prototype of the new configuration was manufactured using some of the processing steps applied in bipolar IC technology by employing four masks. The resistivity of the *n*-Si substrate is $\rho \approx 7.5\ \Omega\cdot$cm ($N_D = n_0 \approx 4 \times 10^{15}$ cm^{-3}). The penetration depth of the current trajectories into the *x*-*y* plane is about 30 µm. The active sensor zone is 80 × 135 µm^2. The essential result is that the sensor is implemented within a single technological cycle. The output characteristics, $V_H(\boldsymbol{B})$, of the configuration are linear and odd when derived from field $\boldsymbol{B}$ and supply I_S.

The sensitivity is $S_{RI} \approx 40$ V/AT. The nonlinearity constitutes no more than NL $\leq 0.2\%$ in field $B \leq \pm 0.3$ T and NL $\leq 0.6\%$ in ± 0.3 T $\leq B \leq \pm\ 0.7$ T. According to the obtained data, the sensitivity temperature coefficient TCs is 0.1%/°C. It was established that the temperature coefficient of resistance R within the range 0 °C $\leq T \leq$ 80 °C is approximately $TC_R \approx 1.1\%$/°C. The initial offset of the new configuration is by about 25% lower than structures similar to the 3C microdevices. The offset voltage is a linear function of the current I_s, Figure 2. The noise behaviour of the device is shown in Figure 3. At low frequencies, the spectrum $f \leq 1.0$ kHz is typical for usual Hall plates, i.e., $1/f$ type. The extracted resolution in terms of the equivalent induction Bmin = $[S_{n,v}(f)\Delta f^2]/S_A$, [T] at current I_s = 4 mA over bandwidth Δf = 5 Hz–400 Hz at the signal-to-noise-ratio S/N = 1 is around $B_{min} \approx 16$ µT.

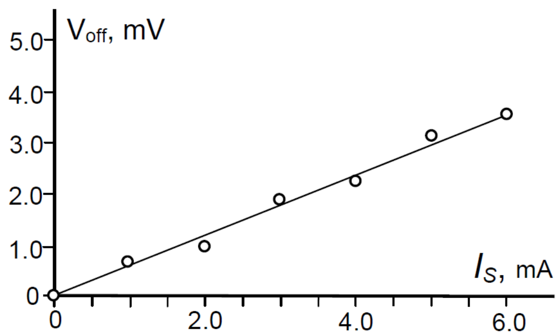

Figure 2. Offset voltage versus bias of current IS at T = 20 °C.

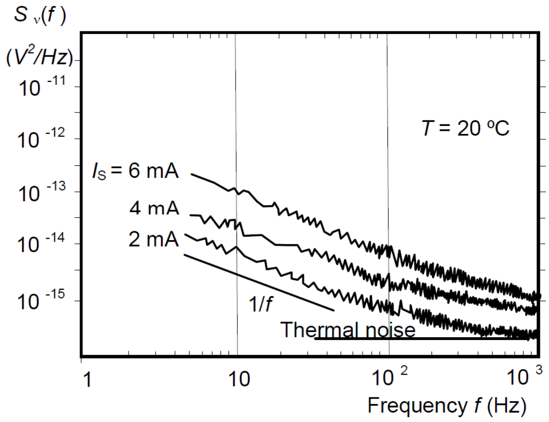

Figure 3. Internal noise power spectral density with the current IS as a parameter.

In conclusion, the transformation of the 3C vertical Hall element into the orthogonal sensor configuration yields a high device performance, which is very promising for applications in automobiles, industrial control systems, consumer devices, and, especially, robotics and robotised surgery.

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