DESIGN AND SIMULATION OF 3D MAGNETIC FIELD SENSORS WITH INTEGRATED MAGNETIC CONCENTRATOR

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I. INTRODUCTION

Today, along with the strong development of the Internet of Things (IoT), new scientific directions are opening up, that is, the development and production of microelectronic sensor devices that combine applications for controlling physical, chemical and biological parameters. Sensors used to measure magnetic field induction have a sensitivity and measurement range limited by the materials used, in addition, their main applications - measuring magnetic fields in a plane, applications in three-dimensional space have many limitations. Therefore, the study of the IC design of a magnetic field sensor in combination with the application of an integrated magnetic concentrator for three-dimensional magnetic field measurement is very relevant.

II. DEVICE STRUCTURE

In this paper, the structure of magnetic field sensors based on high electron mobility transistors (HEMT, High Electron Mobility Transistor) and materials with large band gap GaN is studied. Conduct simulation of the characteristics and calculate the sensor sensitivity values at different polarization conditions. In addition, the sensor is built with a long guide channel for enhanced Hall geometry correction (G_H) combined with a cone magnetic amplifier integrated with the sensor to improve the conversion factor.

Figure 1,a shows the structure of the sensor with the magnetic field components in space, where φ is the angle between the magnetic field component B_Z placed perpendicular to the sensor surface and the effective magnetic field B. Under the influence of the magnetic field component B_Z leads to a current difference between the drain electrodes D_1 and D_2 called the Hall current (I_H) and is expressed by [1]:

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where: μ_H - Hall electronic mobility; B_Z - magnetic field perpendicular to the sensor surface; L, W - sensor length and width; I_D - drain current; G_H - Hall geometry correction factor, this is the ratio of the Hall voltage in an actual semiconductor wafer to an ideal Hall plate of infinite length.

The sensor current difference can be measured across the drains and the sensitivity of the sensor S is calculated according to the following expression:

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where: I_{D1}, I_{D2}: drain current; I_{off}: drain current difference in the absence of a magnetic field.

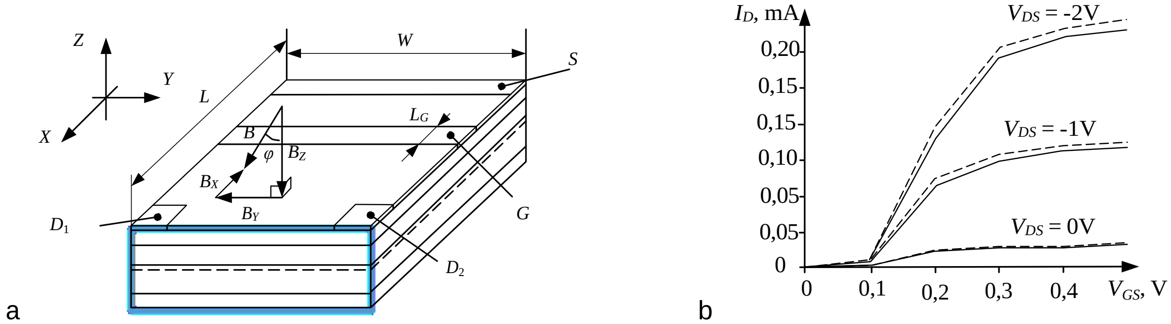

Figure 1. Simulation of the structure (a) and characteristics of the sensor (b)

Simulation of the structure of the Hall sensor with gate length L_G = 5 µm, sensor length L = 65 µm and width W = 20 µm. The distance between the drain electrodes is 10 µm. Figures 1, b show the transfer characteristics of the sensor under the influence of a magnetic field perpendicular to the sensor surface with the value B = 25 mT [3]. The output current from the two drain electrodes depends on the input voltage (V_{GS}) representing the difference in the case of an external magnetic field acting perpendicular to the sensor surface. The relative sensitivity of the sensor obtained at the highest level is S = 15.21%/T and the lowest is S = 5.69%/T at V_{GS} = -2V and V_{GS} = 0V, respectively.

The structure of the magnetic amplifier consists of two cylindrical rods in the form of truncated cones with opposite pointed ends separated by a distance d (Figure 2). The angle between the truncated cone and its axis is denoted ω, the length of each bar L, the clearance between the two rods d and the diameters of the large and small bases of the truncated cone are 2R and 2r respectively. The distance d is limited by the thickness of the Hall sensing element (approximately 0.15 mm).

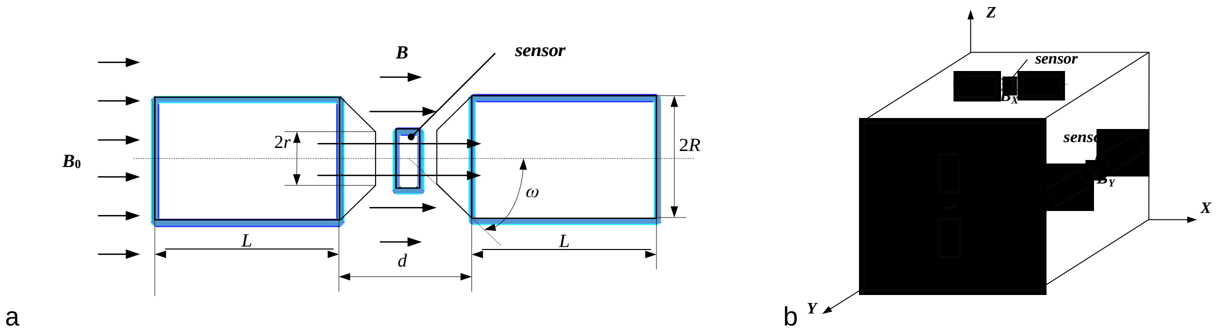

Figure 2. Structure of the integrated magnetic concentrator and 3D magnetic field sensor

Magnetic field gain $K = B/B_0$, this is the ratio between the magnetic field induction in the gap of the magnetic amplifier where the Hall sensor B is installed and the external magnetic field B_0, this is the main parameter of the magnetic amplification. The difficult problem is choosing the material and size for the magnetic amplifier for the magnetic field sensor, but it is important to establish the relationship and influence of the geometrical dimensions on the uniformity magnetic field perpendicular to the sensor surface, thereby providing design principles and sensor optimization [2]. The results by calculation show that with the length of each rod being 100 mm and the spacing 0.15. mm, a flux gain of about 400 times can be achieved.

Figure 2, b depicts the structure of a 3D magnetic field sensor combined with a magnetic field amplifier. Hall sensor probes 0.3×0.3×0.15 mm in size placed in planes in space, created on the basis of AlGaN/GaN heterostructure with magnetic amplifier. These sensors are capable of calculating the components of the magnetic field along the coordinate axes in space.

III. CONCLUSIONS

Study the structure and simulate the properties of Hall sensors based on the operation of high electronic mobility transistors using AlGaN/GaN heterostructured materials. The simulation results show that the relative sensitivity of the sensor obtained at the highest level is $S = 15.21\%/T$ at $V_{GS} = -2V$.

The simulation results contribute to the selection of the amplifier structure in combination with the Hall sensor to ensure the parameters of sensitivity and suitable measuring range. When using magnetic materials increases the gain and can reach a value of about 400 times.

Research on the structure of the 3D magnetic field sensor combined with a magnetic amplifier to increase the sensitivity and measuring range of the magnetic field, from which it is possible to apply the sensor in space for the weak magnetic field measurement range from 0.01 μT to 2 mT.

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