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Sector split-drain magnetic field-effect transistor based on standard CMOS technology

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Abstract

A novel sector split-drain magnetic field-effect transistor (MAGFET), which is compatible with standard 0.6 μm N-well CMOS technology, has been suggested and an analytical model of the sector MAGFET is also developed. The model of sector MAGFET is focused on the effect of primary geometric parameters to sensor sensitivity. In order to verify the advantage of the sector MAGFET, the sector structure is also compared with traditional rectangle structure by the simulations and the experiments. The maximum sensor sensitivity of 3.77%/*T* of the sector MAGFET is obtained by the experimental results and improvements of sensitivity are attributed to sector structure.

Keywords: Split-drain magnetic field-effect transistor (MAGFET); Modeling; Sensitivity

1. Introduction

Split-drain magnetic field effect transistor (MAGFET) is a new kind of magnetic sensor transferring magnetic parameter into electrical signal. In low-frequency applications, the sensitivity of the MAGFET has been shown to be dominated by the flicker (1/*f*) noise, just like the MOS transistor. So MAGFET is suitable for sensing small magnitude magnetic fields [1]. At this level of sensitivity, the MAGFET is suited for applications in uniform magnetic field measurement and magnetic material memory readout [2]. The MAGFET is more attractive to researchers for the applications mentioned above, because integrating this kind of MAGFET on a chip with complex signal-processing circuit requires no modification of standard CMOS technology.

Traditional MAGFET has been structured in rectangle like a Hall plate. Recently Rubio et al. [3] has reported a kind of rectangle MAGFET with a relative sensitivity as high as 3.0%/*T*. Kluge et al. [4] also reported a model for rectangle MAGFET using a geometric correction factor G to express the sensitivity. Based on the results from Rubio et al. and Kluge et al., the sensitivity of MAGFET will be higher when its lateral width of its source region is reduced. A sector MAGFET with smaller source region compared with drain region is suggested in this paper. Its model with maximum theoretical sensitivity and how it depends on the device geometry parameters is also developed.

2. Sector MAGFET description

The sector MAGFET structure suggested in this paper is shown in Fig. 1. These parameters are channel length in radial direction L, radius of source region R, extension angle of source region α as primary parameters, the gap between two drain regions d, and overlap of poly-silicon gate at source and drain region u as a secondary parameter. The device works electrically like a standard MOS transistor, while its magnetic field sensing capability originates in the split drain. The Lorentz force will cause the carriers in MAGFET channel to move perpendicular to channel current, when the vertical magnetic field B was applied on the sensor (shown in Fig. 1). The drain currents from two separate drains with be different

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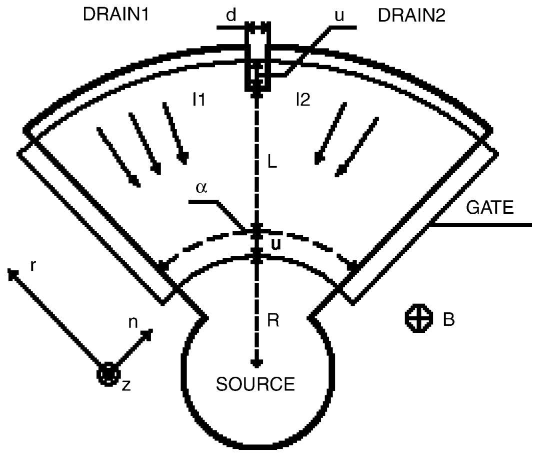

Fig. 1. Layout of sector MAGFET with geometrical parameters.

and its difference is $I_{DIFF} = I_1 - I_2$. The relative sensitivity of the MAGFET can be defined as:

$$S = \left| \frac{1}{I_{DS}} \frac{I_{DIFF}}{B_Z} \right| \quad (1)$$

where B_z is the intensity of magnetic field and I_{DS} the total current $I_{DS} = I_1 + I_2$.

As other researchers have reported the dependency of sensitivity on the primary geometric parameters of the device [3–6], in this article, we want to develop an analytical expression for S, which includes the dependencies on L, R and α. This expression is verified by experimental results. And the sensitivity of sector MAGFET has been compared with traditional rectangle MAGFET.

3. Model of the sector MAGFET

Modeling is based on n-channel MAGFET, however holds similarly for p-channel devices. Because model is focused on the effect of primary geometric parameters to sensor sensitivity, and as Fig. 1 shown, u is much smaller than L ($u \ll L$) and also $d \ll L{\cdot}\alpha$, so the modified sector MAGFET structure layout can be shown in Fig. 2 with channel length

$$L^* = (L + 2u). \quad (2)$$

3.1.1. *Current of sector MAGFET*

In order to get an equation for the sensitivity, an equation for the current difference I_{DIFF} should be need. The general equation for the current density in an n-type semiconductor including the magnetic effects can be taken from [7]

$$\vec{j} = \sigma(B)\vec{E} + \mu_H \sigma(B)\vec{E} \times \vec{B} = \frac{\sigma}{1 + (\mu_H B_Z)^2}(\vec{E} + \mu_H \vec{E} \times \vec{B}). \quad (3)$$

In this equation $\vec{j} = (j_r, j_n)$is the current density, $\sigma(B)$ is the magnetic field dependent conductivity, $\rightarrow E = (E_r, E_n)$is

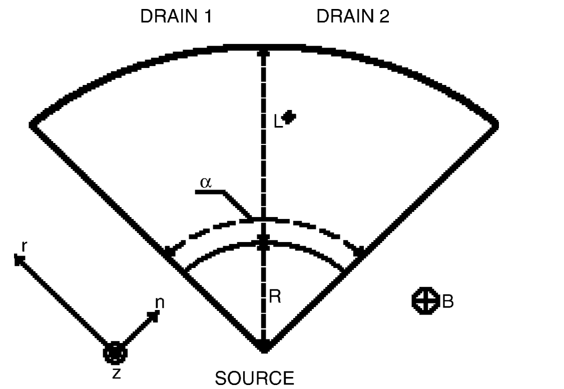

Fig. 2. Modified channel region of the sector MAGFET (the transformed drain distance is zero).

the electric filed, and μ_H is the Hall mobility. The n-component of $\vec{j}$ is responsible for the current deference I_{DIFF}. After neglecting the term $(\mu_H B_z)^2$ due to small magnetic fields, this current deference density can be written as

$$j_n = \sigma(E_n + \mu_H E_r B_z). \quad (4)$$

E_n originates in the Lorentz force and thus can be expressed as $E_n = -G v_r B_z$, where G is the geometric correction factor and v_r the velocity of the charge carriers in the radial direction. G is introduced since we examined nonideal magnetic devices which have their field lines disturbed by electrode contacts [7]. Having in mind that, $\mu_H = \gamma\mu$ with γ being the scattering factor and μ the charge carrier mobility, Eq. (4) can be developed into

$$j_n = -j_r \mu(\gamma - G) B_z. \quad (5)$$

3.1.2. *Geometric correction factor of sector MAGFET*

The geometric correction factor is used to take into account the difference in the field distribution of a real Hall sample (e.g., a Hall plate), compared to an ideal Hall sample. It is important to note that G is not dependent on the thickness of the device it is used upon [7]. This is an important fact for the sector MAGFET model since the thickness of the channel depth is unknown.

The G of rectangle MAGFET has been developed by Ref. [4]. So this paper developed the G of sector MAGFET based on the result of rectangle one. The magnitude of G changes not only due to different geometries of the MAGFET, but also due to the conducting contacts which short-circuit the Hall field near the ends of the probe. This leads to an inhomogeneous behavior of over the radial direction length of the sector MAGFET: G becomes a function of the r-coordinate $G(r)$.

The following equation is valid for the rectangle Hall plate [8]

$$G_{tot} = G\left(r = \frac{L^*}{2}\right) = 0.742\frac{L^*}{W}, \quad \left(\frac{L^*}{W}\right) < 0.35 \quad (6)$$