# The Offset of Magnetotransistors

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***Abstract* — An essential parameter in the setting up of the performance of the measurement systems that uses Hall microsensors is the magnetic offset of such devices.**

**This paperwork presents the structure, the operating conditions, and the main characteristics for the lateral bipolar magnetotransistors and for double drain magnetotransistors.**

**By using numerical simulation, the values of the offset-equivalent magnetic induction for the two analysed devices are compared and it is also emphasized the way in which choosing the geometry and the material features allows getting high-performance sensors.**

## I. General characterization of the double drain magnetotransistors

The double-drain MOS device (figure 1) is a MOSFET with two adiacent drain regions replacing the conventional single drain region, the total channel current being shared between these regions [1]

The result of the bias is the linear region is the obtained of a continuous channel of approximately constant thickness, which can be assimilated with a Hall plate.

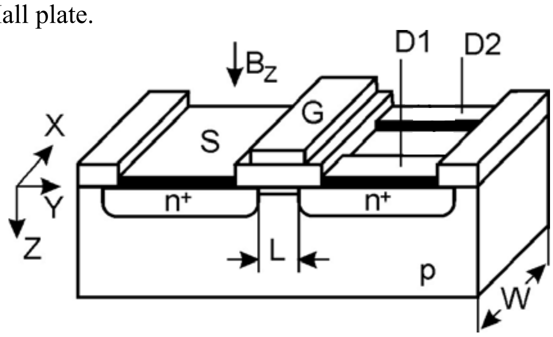


Fig. 1. Double-drain MOSFET magnetotransistor

The deflection of current lines appears under the action of a magnetic field $B_{\perp}$, perpendicular to the device surface. The current deflection causes an imbalance between two drain currents:

$$\Delta I_D = I_{D1}(\overline{B}) - I_{D1}(0) = I_{D2}(\overline{B}) - I_{D2}(0) \quad (1)$$

Since the output signal of the double-drain MOS magnetotransistors consists of the current variation between its terminals, this device operates in the Hall current mode. Using the features of dual Hall devices, and the Hall current expression it results [2]:

$$\Delta I_D = \frac{I_H}{2} = \frac{1}{2}\mu_{H_{Ch}} \cdot \frac{L}{W} \cdot G \cdot I_D \cdot B_{\perp} \quad (2)$$

where $\mu_{H_{Ch}}$ is the carriers Hall mobility in the channel, and $G$ denotes the geometrical correction factor.

The supply-current-related sensitivity of the devices is defined by:

$$S_1 = \frac{1}{I_D} \cdot \left| \frac{\Delta I_D}{B_{\perp}} \right| = \frac{1}{2}\mu_{H_{Ch}} \cdot \frac{L}{W} G \quad (3)$$

and depends on the channel geometry.

## II. The offset equivalent magnetic induction

The difference between the two drain currents in the absence of the magnetic field is the offset collector current.

$$\Delta I_{D_{off}} = I_{D1}(0) - I_{D2}(0) \quad (4)$$

The causes consist of imperfections specific to the manufacturing process: the misalignment of contacts, the non-uniformity both the material and channel depth, the presence of some mechanical stresses combined with the piezo-effect.

To describe the error due to the offset it is determined the magnetic induction, which produce the imbalance $\Delta I_C = \Delta I_{Coff}$ . The offset equivalent magnetic induction is expressed by considering the relation (3):

$$B_{off} = \frac{\Delta I_{D_{off}}}{S_I I_D} = \frac{2}{\mu_{Hn}} \cdot \frac{\Delta I_{D_{off}}}{I_D} \cdot \left( G \frac{L}{W_E} \right)^{-1} \quad (5)$$

Considering $\Delta I_{D_{off}} = 0.10 \mu A$ and assuming that the low magnetic field condition is achieved in figure 2 is presented the dependence of $B_{off}$ on $I_D$ for three magnetotransistors with the same geometry *W/L=0.5* realised from different materials:

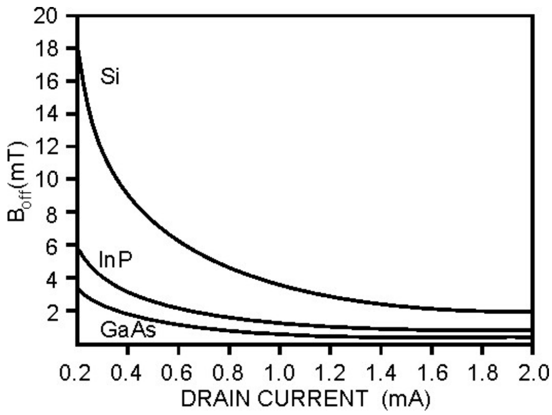


Fig. 2. The $B_{off}$ depending on the drain current for three devices of different materials

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MDD1: Si with $\mu_{H_{Ch}} = 0.07 m^2 V^{-1} s^{-1}$;

MDD2: InP with $\mu_{H_{Ch}} = 0.23 m^2 V^{-1} s^{-1}$;

MDD3: GaAs with $\mu_{H_{Ch}} = 0.43 m^2 V^{-1} s^{-1}$;

The geometry influence upon $B_{off}$ is shown in figure 3 by simulating three magnetotransistors structures realised from silicon and having different $W/L$ ratios [3].

$$MDD1: \frac{W}{L} = 0.5; \quad G\frac{L}{W} = 0.73;$$

$$MDD2: \frac{W}{L} = 1; \quad G\frac{L}{W} = 0.67;$$

$$MDD3: \frac{W}{L} = 2; \quad G\frac{L}{W} = 0.46.$$

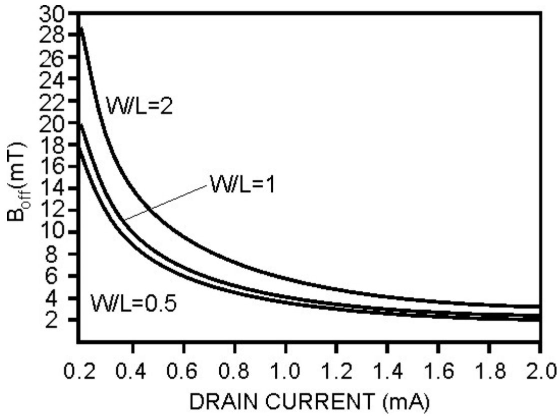


Fig. 3. The $B_{off}$ depending on the drain current for three devices of different geometry

If the width of the channel is maintained constant, $B_{off}$ increases as the channel length decreases. So that minimum values for the offset equivalent induction are obtained with the device which has $L = 2W$, and in the MDD3 device these values are 53.5% bigger.

## III. General caracterisation of the lateral bipolar magnetotransistor

Figure 4 illustrates the cross section of a magnetotransistors operating on the current deflection principle [4].

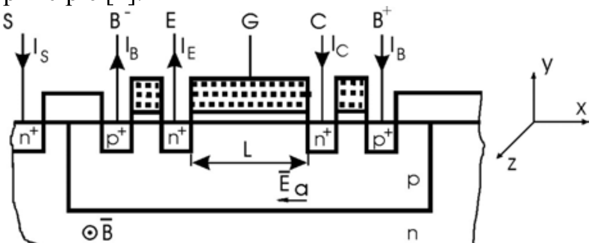


Fig. 4. Cross section through a lateral magneto-transistor in CMOS technology

This device has the structure of a long channel MOS transistor, but operates as a lateral bipolar transistor with a drift-aided field in base region.

The device is situated in a *p*-well, serving as the base region of the transistor. The two base contacts $B^+$ and $B^-$, allow the application of an accelerating voltage for the minority carriers injected into the base region. The two $n^+$ region laterally separated by the length of base along the distance *L*, serve as the emitter E and primary collector C. The substrate S works as the secondary collector.

In order to describe the qualitative operation of the device, let us assume that it is adequately biased for the forward active operation.

Owing to the accelerating field $\overline{E}_a$ in the base region, the most part of electrons injected into the base region drift mainly along the base length, and are collected by collector C, producing collector current $I_C$. However, some of the which diffuse downwards, are collected by the secondary collector S, producing the substrate current $I_S$. The rising of ratio between the useful current $I_C$ and the parasite current $I_S$, is determined by the accelerating field. A magnetic induction $\overline{B}_\perp$ perpendicular to the figure plane, modulates the distribution of the emitter current $I_E$ among $I_C$ and $I_S$. The modulation in the collector current $I_C$ is used as the sensor signal.

If the acceleration field $\overline{E}_a$ in the base region is very small the electrons moving essentially by diffusion, the transverse Hall current will be [5]:

$$I_H = I_Y = (L/Y) I_C \mu_{Hn} B_\perp = \Delta I_C \qquad (6)$$

where $\mu_{Hn}$ is the Hall mobility of electrons in the *p*-well, and *Y* is a geometrical parameter given approximately by $y_{jn} < Y < y_{jp}$. Here $y_{jn}$ and $y_{jp}$ denote the junction depths of the collector region and the *p*-well respectively.

## IV. The sensor response and the sensitivity

A magnetotransistor may be regarded as a modulation transducer that converts the magnetic induction signal into an electric current signal.

This current signal or output signal is the variation of collector current, caused by induction $\overline{B}_\perp$.

The sensor response is expressed by:

$$h(B) = \frac{\Delta I_C}{I_C} = \frac{L}{Y} \mu_{Hn} \cdot B \qquad (7)$$

and it is linear for induction values which satisfy the condition: $\mu_H^2 \cdot B_\perp^2 << 1$. In figure 5 it can be seen the geometry influence on $h(\overline{B})$ values for three magnetotransistor structures, realized on silicon

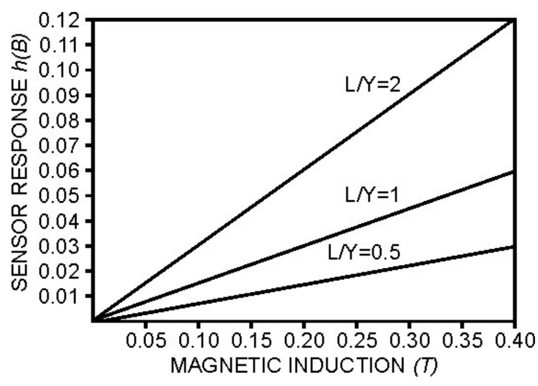


Fig. 5 The *h(B)* depending on *B* for three devices of different geometry

($\mu_{Hn} = 0.15 m^2 V^{-1} s^{-1}$) and having different ratios $L/Y$ $(L = 50 \mu m)$.

MGT$_1$: $\frac{L}{Y} = 0{,}5$ ; MGT$_2$: $\frac{L}{Y} = 1$ ; MGT$_3$: $\frac{L}{Y} = 2$ ;

For the same geometry ($L/Y = 0.5$) the sensor response depends on material features. In figure 6 there are shown $h(\overline{B})$ values for two sensor structures realized on Si ($\mu_{Hn} = 0.15 m^2 V^{-1} s^{-1}$) and GaAs ($\mu_{Hn} = 0.80 m^2 V^{-1} s^{-1}$).

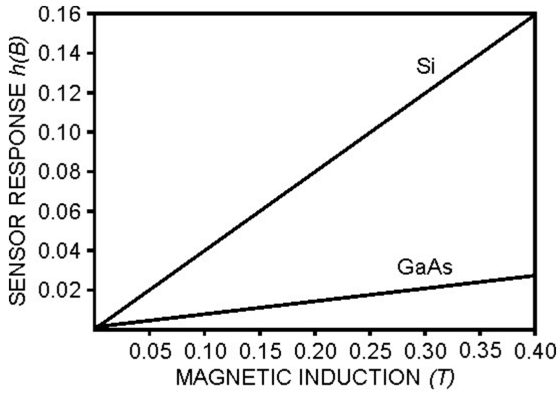


Fig. 6. The *h(B)* on *B* on the two sensors of different materials

We can see that the sensors made of high mobility materials have superior response. For the same magnetic induction $B = 0.2T$ at the GaAs device, $h(\overline{B})$ increases 5.6 times comparated to that value for the silicon.

The magnetic sensitivity related to the devices current is defined as foloows:

$$S_I = \frac{1}{I_C}\left|\frac{\Delta I_C}{B}\right| = \frac{L}{Y}\left|\mu_{Hn}\right| \quad (8)$$

For a given induction $(B = 0.4T)$ and at given collector current $I_C = 1mA$, the sensitivity depends of the device geometry and the material properties. In table I are presented the obtained values for five magnetotransistors structures.

TABLE I. THE NUMERICAL VALUES OF THE SUPPLY-CURENT RELATED SENSITIVITY

| **MGT** | $L/Y$ | $\mu_{Hn}$ $(m^2V^{-1}s^{-1})$ | $S_I(T^{-1})$ |
|---|---|---|---|
| MGT$_1$ (Si) | 3 | 0.15 | 0.45 |
| MGT$_2$ (Si) | 1 | 0.15 | 0.15 |
| MGT$_3$ (Si) | 0.5 | 0.15 | 0.075 |
| MGT$_4$ (GaAs) | 3 | 0.80 | 2.40 |
| MGT$_5$ (GaSb) | 3 | 0.50 | 1.50 |
| | | | |

## V. THE OFFSET EQUIVALENT MAGNETIC INDUCTION

For bipolar lateral magnetotransistor presented in figure 4 the offset current consists in the flow of minority carriers which, injected into the base region in absence of magnetic field diffuse downwards and are collected by the secondary collector S.

The main causes of the offset are due to the misalignment of contacts to non-uniformity of the thickness and of the epitaxial layer doping.

Also a mechanical stress combined with the piezo-effect, may produce offset.

To describe the error due to the offset it is determined the magnetic induction, which produces the imbalance $\Delta I_C = \Delta I_{Coff}$ . The offset equivalent magnetic induction is expressed by considering the relation (8):

$$B_{off} = \frac{\Delta I_{C_{off}}}{S_I I_C} = \frac{1}{\mu_{Hn}} \cdot \frac{\Delta I_{C_{off}}}{I_C} \quad (9)$$

Considering $\Delta I_{Coff} = 0.10 \mu A$ and assuming that the low magnetic field condition is achieved, in figure 7 is presented the dependence of $B_{off}$ on $I_C$ for three magnetotransistors with the same geometry $L/Y = 0.5$ realized from different materials:

MGT1: Si with $\mu_{Hn} = 0.15 m^2 V^{-1} s^{-1}$;

MGT2: GaSb with $\mu_{Hn} = 0.50 m^2 V^{-1} s^{-1}$;

MGT3: GaAs with $\mu_{Hn} = 0.85 m^2 V^{-1} s^{-1}$;

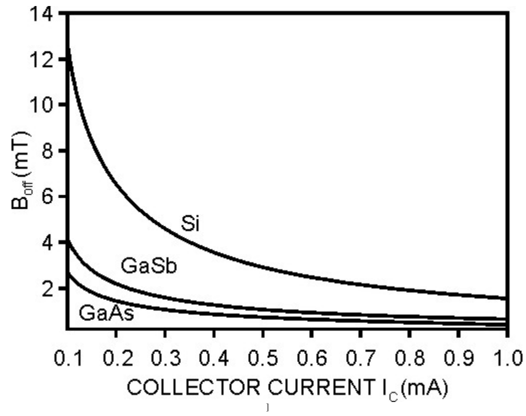


Fig. 7. The $B_{off}$ depending on the collector current $I_C$ for three devices of different materials

The offset-equivalent magnetic induction lowers with the increase of carriers’ mobility.

So for the same collector current *Ic=0.1mA* the $B_{off}$ value of the GaAs device decreases by 70% as compared to that of the silicon device.

## VI. CONCLUSIONS

The analysis of the characteristics of the double drain magnetotransistor shows that the $W/L = 0.5$ ratio is theoretically favourable to high performance regarding the offset equivalent magnetic induction.

Also, substituting the silicon technology by using other materials such as GaAs or InSb with high carrier mobility values assure higher characteristics of the sensors.

The offset equivalent magnetic induction lowers with the increase of carriers mobility, this increase being significant for drain currents of relatively low values. So for the drain current $I_D = 0.2mA$, the offset equivalent magnetic induction value of the GaAs device decreases by 81.8% as compared to that of the silicon device.

Similar findings are outlined in this paper bipolar lateral magnetotransistor too.

## REFERENCES


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