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Design and analysis of MOS based Magnetic Field Sensor

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ABSTRACT

Magnetic sensors are widely used in various applications such as consumer electronic products (mobile phones, laptops), biomedical applications (brain function mapping), navigation, vehicle detection, mineral prospecting, non-contact switching (keyboard), contactless temperature measurement, wireless sensor network etc. Sensitivity of MagFET devices towards magnetic field, depends on the shape, dimensions VGS, VDS. In this paper we have measured effect of Physical design of gate on sensitivity of MagFET.

***Keywords*:** Hall Effect, Magnetic sensor, MagFET device, CMOS Technology, Lorentz force

1. INTRODUCTION

Magnetic Field Effect transistor (MagFET) is unipolar transistor having one source & splitted drain. It is fully compatible with electronics devices because they share same substrate. There are many devices such as slider & flap mobile phone, laptops in which we have to measure magnetic field intensity to do desire work.

When Magnetic Field is absent then it works normally as MOSFET but when we apply external orthogonal magnetic field then due to Lorentz force some part of current is deviated from one drain to another. We measure this current deviation and get sensitivity towards

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magnetic field. The advantage of the MagFET is it can be replace as electric to magnetic sensing element and vice versa [1-6].

2. WORKING PRINCIPLE OF MAGFET

When orthogonal magnetic field is applied to the channel, the carriers are deflected due to Lorentz's force. The split-drain MAGFET transistor senses the magnetic field and converts it into a corresponding electrical signal. When electric charge q moving with speed V in presence of external magnetic field B then charges deflected from their direction by the Lorentz force F.

$$F = q \cdot E_H + q \cdot (V \times B)$$

V is average drift velocity of electron along the direction of drain. $V = \mu n \cdot E_E$ μn is drift mobility of electron in channel and EE is lateral electric field parallel to channel (due to drain voltage) & Current density Jn is defined as.

$$Jn = n \cdot q \cdot \mu n \cdot E_E$$

The magnetic part of Lorenz force pushes electron towards one drain to another drain and creates some electron concentration gradient due to this phenomena Hall electric field (E_H) is appears between edges of drain. Force due to E_H is responsible for charge decrement at edges of drain and equilibrium is established.

$$F = q \cdot E_H + q \cdot (V \times B) = 0$$

$$E_H = - (V \times B)$$

$$E_H = - \mu Hn (E_E \times B)$$

μHn is Hall mobility for electron and it is different from drift mobility.

$$\mu Hn = rH.\ \mu_n$$

where rH is Hall scattering factor. Its value depends upon thermal motion of electron. Drain current deviation (ΔI) is related to Hall electric field.

$$E_H = - rH\ (Jn \times B)\ /n.q$$

We conclude that Hall electric field is linear function of electron mobility, lateral electric field, and external magnetic field but inversely to carrier concentration.

The sensitivity of sensor depends on several factors e.g. the channel length and width, drain gap, source and drain contact sizes and the biasing conditions (V_{GS} and V_{DS}) and can be expressed by following equation. The quantity of current deviation (ΔI) is calculated by relative sensitivity of MagFET.

Where I_D is the bias current of MagFET, S is the relative sensitivity of MagFET, and B is the perpendicular magnetic field. If we increase the length of channel, Lorentz force will acting for longer time and we get appreciable amount of current deviation. Although we require long channel it will give smaller bandwidth, lesser chip density & increase noise level of device.

3. DESIGN METHOD

MagFET is very susceptible to its geometry. There are mainly three parameter which effect sensitivity significantly drain gap length, drain gap width, and aspect ratio. We have measured two types of gate design concave & convex. Concave MagFET drain gap region does not covered with SiO_2 & polysilicon region but in convex MagFET is covered. We used rectangular copper wire to produce external orthogonal magnetic field.

$$\Delta I = B \cdot S \cdot I_D$$

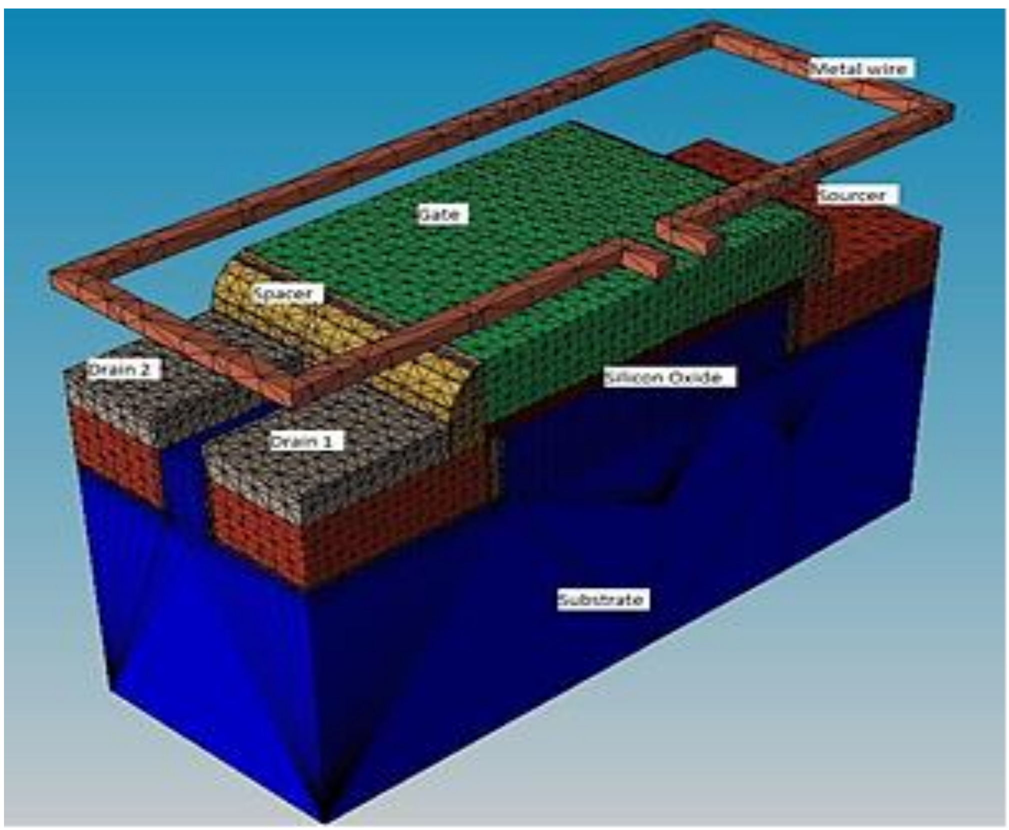

Fig. 1. Geometrical Design of MagFET

In Fig. 1 MagFET comprises SiO_2 & Si_3N_4 material which is used as gate oxide and spacer respectively. Source length is 40 µm, width is 75 µm and doping depth is 20 µm. Drain1 and Drain2 have same dimension. Both have length 40 µm, width 30 µm and doping depth is 20 µm. We have chosen drain gap length 10 µm, 20 µm, 30 µm, 40 µm & drain gap width 5 µm, 10 µm, 15µm. Channel design and concentration profile of MagFET shown in Fig. 1 is listed in Table 1.

Table 1. Device design parameters

S. No.	Parameter	Value [unit]	
1.	Gate Length	100	[µm]
2.	Channel Length	90	[µm]
3.	Channel width	75	[µm]
4.	Gate oxide thickness	2	[µm]
5.	Spacer thickness	10	[µm] each side
6.	Drain gap width	15	[µm]
7.	Drain gap length	30	[µm]
8.	Gate overlap	5	[µm] each side
9.	Substrate Doping	1×10^{17}	[cm^{-2}]
10.	S/D Doping	5×10^{19}	[cm^{-2}]
11.	S/D Extension Region	5×10^{18}	[cm^{-2}]

When we apply magnetic field of 1T then due to Lorentz force current in Drain2 (I_{d2}) is increased & simultaneously current in drain1 (I_{d1}) decrease. We get current difference $\Delta I = I_{d2} - I_{d1}$. When voltage V_{GS} is 1V and V_{DS} 1V then got current I_{d1} 4.52 µA and current I_{d2} 1.46 µA & sensitivity $0.33T^{-1}$.

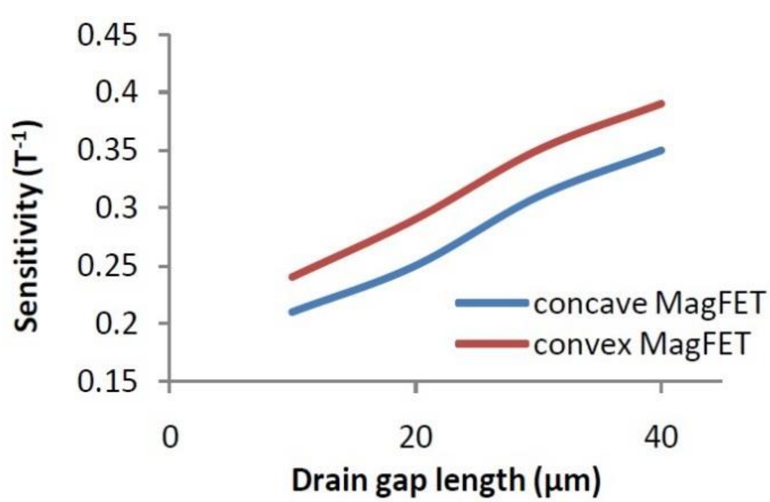

Fig. 2. Variation in Sensitivity with Drain gap length (d)

Fig. 2 & 3 gives sensitivity of MagFET with variation of drain gate length when we fixed drain gap width at 10 μm.

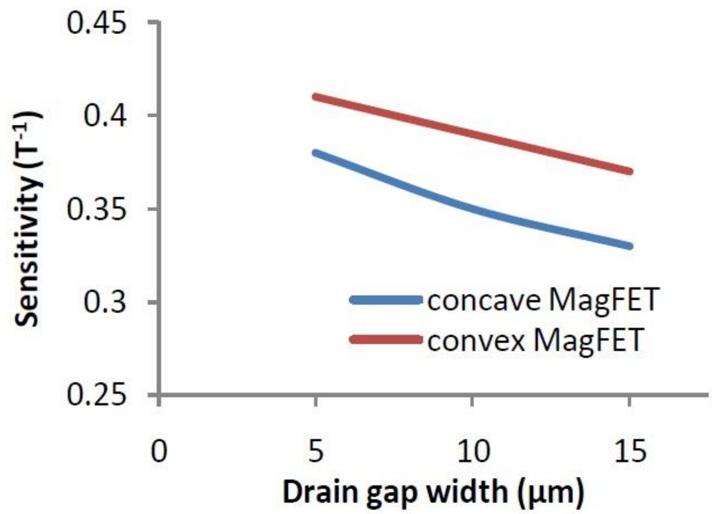

Fig. 3. Variation in Sensitivity with Drain gap width (u)

4. CONCLUSIONS

We saw sensitivity of Convex MagFET is greater than concave MagFET. If we look for design issue then drain gap width should minimum because we are giving more space for charge deviation and drain gap length maximum because we provide maximum time & length for current deviation. Convex MagFET is preferred at those places where we have to achieve higher sensitivity but its performance inhibits from linearity. If we don't want to avoid linearity property then we have to use Concave MagFET. In industry where linearity is major issue Concave MagFET is best option.

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