Multiple-Gate Split-Drain MOSFET Magnetic-Field Sensing Device and Amplifier

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ABSTRACT

A new split-drain MOSFET magnetic-field sensing device is reported which uses multiple gates to establish a longitudinal electric field in the channel. A relative sensitivity of 185mA/AT was measured for a double-polysilicon, multiple-gate, split-drain MOSFET. A *triple-drain* multiple-gate MOSFET device achieved relative sensitivities greater then 10,000mA/AT. A new amplifier circuit for the multiple-gate, split-drain device achieved an absolute sensitivity of 10V/T at a 400nA bias current corresponding to a relative sensitivity of 2.5×10^7 V/AT. The intrinsic power dissipation of the magnetic amplifier sensor is as small as $8\mu W$.

INTRODUCTION

A common method of implementing a magnetic field sensor is the split-drain MOSFET magnetic field sensor (MAGFET) which has two drain separated by an isolation region [1,2]. In this device, a magnetic field perpendicular to the channel causes a Lorentz deflection of the current flow towards one of the two drains and this slight imbalance in the drain currents is used to sense the magnetic field strength. The primary attributes of the MAGFET which makes it a promising magnetic field sensor are its compatibility with MOS technology and its good linearity [2].

A new split-drain MOSFET magnetic-field sensing device is reported which uses multiple gates, with each gate along the channel biased at a higher voltage, to establish a longitudinal electric field in the channel (Fig. 1). The high longitudinal electric field increases the carrier velocity and thus the Lorentz deflection of carriers. This device is similar in concept to the resistive-gate split-drain MOSFET magnetic-field sensing device reported by Gill and Heasell [3] except for the replacement of the resistive gate by the multiple gates. Unlike the Gill device, this magnetic field sensor can be fabricated using currently available CMOS foundry processes. Our device was fabricated using the MOSIS $2\mu m$ n-well, double-poly, CMOS process, including a n-buried channel layer to obtain high electron mobilities. Bias voltages for the gates were established by an n-well resistor voltage-divider with one terminal of the resistor connected to a left gate bias, V_{GL}, and the other terminal connected to a right gate bias, V_{GR}, with the internal gates connected along the voltage-divider.

DEVICE GEOMETRY

Two basic types of multiple gate, split-drain MOSFET magnetic field sensing devices were evaluated. These device types were double-polysilicon devices, as shown in Fig. 1, and single polysilicon devices with a $2\mu m$ separation between the each of the first polysilicon gate layers. The relative sensitivity values obtained for the single polysilicon layer MOSFET magnetic field sensing devices were approximately a factor of three below those obtained for the double-polysilicon gate devices, possibly because of potential barriers formed in the intra-gate regions which allow the deflected carriers to re-equilibrate.

The double-polysilicon gate devices have a channel length $45\mu m$ and a width of $30\mu m$. The first polysilicon gate lengths and separation between the gates are both $6\mu m$ with the second polysilicon layer overlapping the first polysilicon layer by $2\mu m$. A $4\mu m$ wide field oxide channel-stop region separates the two drains.

The double-polysilicon, triple-drain MOSFET magnetic device have gate length of $6\mu m$, a gate separation of $6\mu m$, a total channel length of $45\mu m$, a center drain width of $30\mu m$ and each of the outside drains have a width of $10\mu m$. A $4\mu m$ wide field oxide channel-stop region separates each of the two outside drains from the center drain.

EXPERIMENTAL RESULTS

The highest relative sensitivity, defined as

$$S_R = \frac{I_{D1}-I_{D2}}{(I_{D1}+I_{D2})B_z}$$

where I_{D1} and I_{D2} are the drain currents and B_z is the magnetic field strength, for the double-polysilicon multiple-gate device were found for a left gate biasing condition in which the device buried channel was nearly pinched off as shown in Fig. 2 (source-to-substrate basis of -4V). The relative sensitivity for the double-polysilicon, multiple-gate device increased by greater than a factor of three as the bias voltage difference, ΔV_G, between V_{GL} and V_{GR} is increased from -4 to 10V (Fig. 3). A peak relative sensitivity of 185mA/AT was measured. This relative sensitivity value is approximately a factor of four greater than conventional MAGFET sensitivities [1,2] and is the highest reported relative sensitivity for a silicon split-drain MOSFET device to our knowledge. Figure 3 shows the linearity of the double-polysilicon, multiple-gate magnetic sensor.

A *triple-drain,* multiple-gate MOSFET devices was also evaluated. This device had a center drain that was biased at a higher voltage than the two outside drains. At appropriate right gate bias voltages, the two outside drains act as sources with the center drain collecting the carriers. For an optimum right gate bias, the undeflected current to the two outside drains is canceled by the current sourced from the outside drains to the center drain. Relative sensitivities greater then 10,000mA/AT (Fig. 5) were measured in this device. In contrast with the triple-drain device reported by Gill and Heasell [1], the drain current imbalance in our devices was small ($< 1.5\mu A$).

A new amplifier circuit (Fig. 6) has been developed for sensing the output current of the multiple-gate, split-drain magnetic sensor. The circuit consists of an operational transconductance amplifier (OTA) with the multiple-gate, split-drain device used as the driver transistors. An important feature of this amplifier design is that the two drains are biased at approximately the same potential. This feature is important for split-drain devices because an asymmetric bias condition can lead to a parasitic conductance between the split drains [2]. Another feature of this amplifier design is that the drains are biased at approximately a threshold voltage drop from V_{DD} allowing a high longitudinal electric field in the channel. A variable current source was used at the output to adjust the output voltage to the mid range of the amplifier. The absolute sensitivity achieved was 10V/T at a 400nA bias current corresponding to a relative sensitivity of 2.5×10^7 V/AT. The absolute sensitivity is approximately a factor of <u>six</u> higher and the relative sensitivity approximately <u>three orders-of-magnitude</u> higher than previously reported for magnetic sensor amplifiers [4]. The intrinsic power dissipation of the OTA amplifier (excluding the dissipation in the resistive voltage-divider string) is as small $8\mu W$. The power dissipation of the resistive voltage-divider string is $120\mu W$ for a 10V bias. Potentially lower power dissipation levels can be achieved by the use of "pinched" n-well resistors or internally generated voltage sources. Figure 7 shows the magnetic amplifier output voltage as a function of the tail current, I_B, for .15T field showing operation at 250nA current levels. Figure 8 shows the measured linearity of the amplifier for bias currents of 300nA and $1\mu A$.

A new magnetic field sensing OTA design is currently being fabricated which should not require the use of the variable current source at the output. The new OTA design uses a current-to-voltage stage at the output of the OTA similar to that used by Wang [5,6].

CONCLUSIONS

A new split-drain MOSFET magnetic-field sensing device is reported which uses multiple gates to establish a longitudinal electric field in the channel. A relative sensitivity of 185mA/AT was achieved for a double-polysilicon, multiple-gate, split-drain MOSFET. This sensitivity is approximately a factor of four greater than conventional MOSFET split drain sensitivities. A triple-drain, multiple-gate MOSFET device achieved relative sensitivities greater then 10,000mA/AT. A new magnetic sensor amplifier circuit achieved an absolute sensitivity of 10V/T at a 400nA bias current corresponding to a relative sensitivity of 2.5×10^7 V/AT. The absolute sensitivity is approximately a factor of six higher and the relative sensitivity approximately three orders-of-magnitude higher than previously reported for magnetic sensor amplifiers [1]. The intrinsic power dissipation is as small as $8\mu W$.

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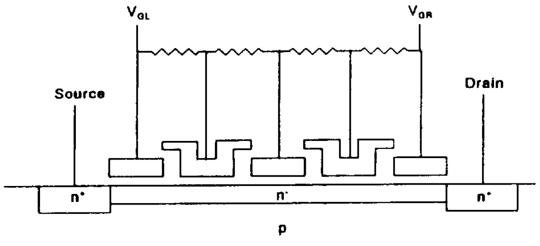

Fig. 1. Cross section of a double-polysilicon, multiple-gate, split-drain magnetic field sensor.

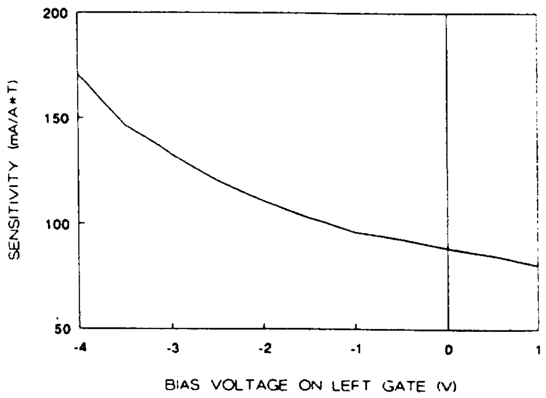

Fig. 2. Relative sensitivity, S_R, versus left gate voltage, V_{GL}, for a double-polysilicon, multiple-gate, split-drain MOSFET magnetic field sensor($V_D = 10V$, $VGR = 15V$, $V_S = 0V$, $V_{SUB} = -4V$).

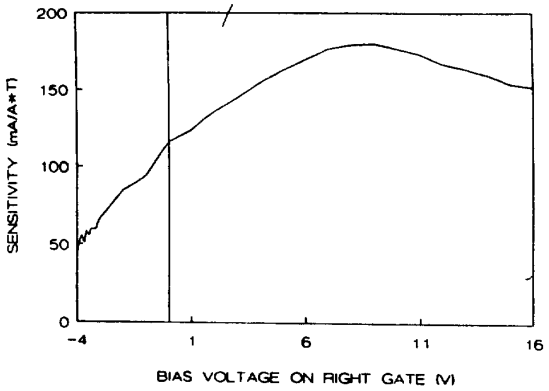

Fig. 3. Relative sensitivity, S_R, versus right gate voltage, V_{GR}, for a double-polysilicon, multiple-gate split-drain MOSFET magnetic field sensor ($V_D = 10V$, $VGL = -4V$, $V_S = 0V$, $V_{SUB} = -4V$).

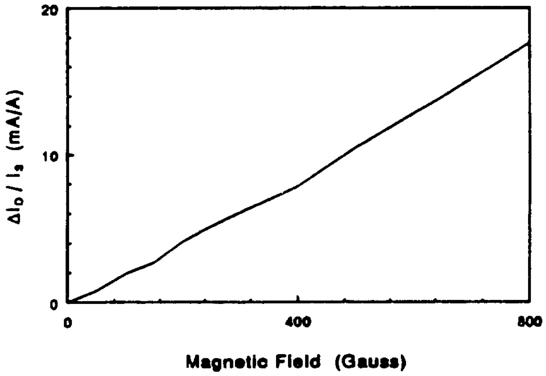

Fig. 4. Measured response of split-drain to an applied magnetic field.

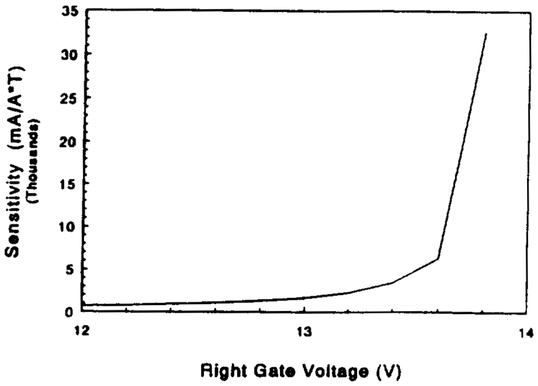

Fig. 5. Relative sensitivity, S_R, versus right gate voltage, V_{GR}, for a multiple-gate, triple-drain MOSFET magnetic field sensor.

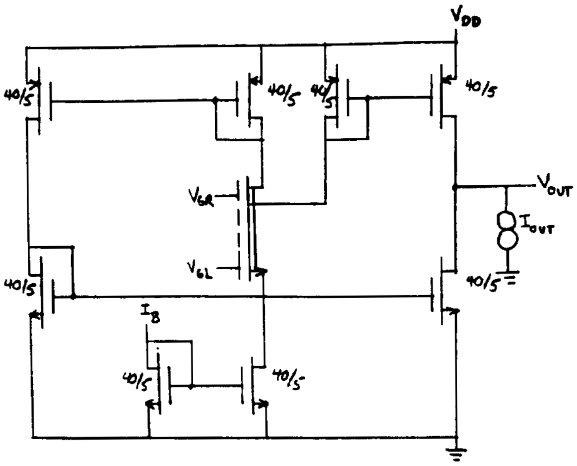

Fig. 6. Operational transconductance amplifier magnetic sensor circuit.

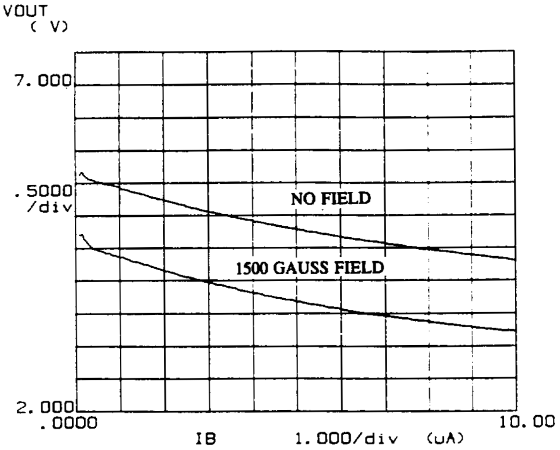

Fig. 7. Output voltage of the magnetic sensor OTA as a function of tail current, I_B, (VGL=-.8V, VGR=7.5V, VDD=10V, V_{SUB}=-1V, I_{OUT}=0A).

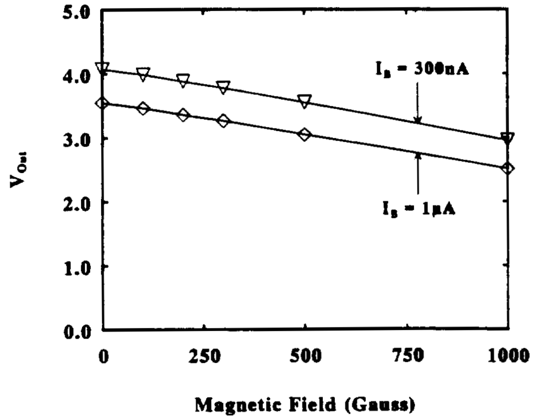

Fig. 8. Output voltage of the magnetic sensor OTA as a function of magnetic field.