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A numerical investigation on effects of lateral Si/SiO2 interface traps on magnetic sensitivity of sectorial SD-MAGFET

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Abstract:

Split-drain magnetic field-effect transistor (SD-MAGFET) has been widely used as magnetic field sensors, current sensors and temperature-stable arrays due to its small size and CMOS compatibility [1]–[2][3]. Previous work suggested that its sensitivity hysteresis could be caused by the Si/SiO2 interface traps at the sidewalls of the conduction channel [4]. However, the effects of these interface traps on the magnetic sensitivity have not been studied in detail. In this work, the effects of trap type, trap density and trap energy are investigated by Silvaco TCAD.

Keywords: Electron traps, Sensitivity, Saturation magnetization, Magnetic hysteresis, Magnetic sensors, Magnetic devices

Introduction

Split-drain magnetic field-effect transistor (SD-MAGFET) has been widely used as magnetic field sensors, current sensors and temperature-stable arrays due to its small size and CMOS compatibility [1]–[2][3]. Previous work suggested that its sensitivity hysteresis could be caused by the Si/SiO2 interface traps at the sidewalls of the conduction channel [4]. However, the effects of these interface traps on the magnetic sensitivity have not been studied in detail. In this work, the effects of trap type, trap density and trap energy are investigated by Silvaco TCAD.

Numerical Model

The interface traps at the lateral side of the sectorial SD-MAGFET has a significant impact on the carrier motion in the channel (Figure 1). Acceptor traps (AT) and donor traps (DT) can respectively capture and emit electrons, and this trapping effect will interact with the Hall effect when the device is exposed to a magnetic field. The acceptor traps are neutral when empty and negatively charged when filled with electrons from the conduction or valence band. On the other hand, the donor traps are positive when empty and neutral when filled with electrons from the conduction or valence band (Figure 2). The probability of ionization for the traps depends on the capture cross sections of electron and hole. They are assumed to be constants for all trap energy levels in the forbidden band and are based on the analysis exploit by Simmons and Taylor [5].

Results and Discussion

Figure 3 exhibits that acceptor-like interface trap and negative oxide charge have same effect on the magnetic sensitivity of the device (for two densities of 1×1011cm−2 and 1×1012cm−2). This is also true between donor-like interface trap and positive oxide charge. Therefore, the filled acceptor traps (after capturing electrons from the channel) act like negative oxide charges to decrease the total drain current by depleting the n-channel near the sidewalls, and increase the drain-current difference by increasing the bending of electron path in the n-channel, both resulting in higher magnetic sensitivity. On the other hand, the emptied donor traps (after releasing electrons to the n-channel) behave like positive oxide charges to increase the total drain current by enhancing the n-channel near the sidewalls, and decrease the drain-current difference by reducing the bending of the electron path in the n-channel, both leading to lower magnetic sensitivity.

In Figure 4, the magnetic sensitivity with acceptor traps increases dramatically and then saturates because the p-Si near the sidewalls changes from depletion to accumulation. For donor trap, the abrupt drop in magnetic sensitivity is due to large current increase resulted from heavy inversion of the p-Si near the sidewalls.

Figure 5 presents the magnetic sensitivity as a function of the trap energy. Different donor trap levels (EtD) and acceptor trap levels (EtA) (0.5 eV to 1.0 eV) are applied to the energy gap (see Figure 2). EtD and EtA are relative to the valance-band top and conduction-band bottom respectively. For donor traps near to the middle of the energy gap Ei, the probability that the donor trap can emit an electron is smaller than that far above Ei. Therefore, as EtD increases, more traps can emit electrons leading to lower magnetic sensitivity (like the oxide charge in Figure 3). On the other hand, for larger EtA, the AT trap level lies near to the valance band and so are more likely to capture electrons to form negative charges, resulting in higher magnetic sensitivity (like the oxide charge in Figure 3).

Conclusion

The interface traps at the lateral side of sectorial SD-MAGFET have been investigated in detail, including their most important parameters: trap type, trap density and trap energy. The ionized acceptor traps at the lateral interface are negatively charged and so increase the magnetic sensitivity by increasing IH and decreasing IDS. However, the ionized donor traps are positively charged and thus decrease the magnetic sensitivity by decreasing IH and increasing IDS. Higher sensitivity is observed when the acceptor traps lie nearer to the valance band, or the donor traps are farther from the conduction band. This work can provide better understanding on the lateral interface properties of the sectorial SD-MAGFET and provide a design guide for improving its performance.

Figures

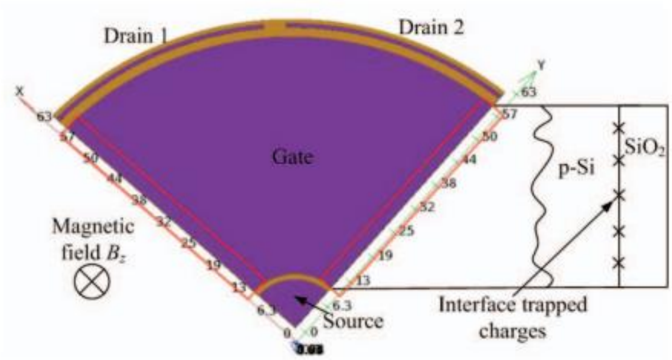

Figure 1. Top view of sectorial SD-MAGFET with 90° source angle, aluminum electrodes for source, gate, drain 1 and drain 2 (x and y are in um). Under a magnetic field Bz normal to the channel, the two drains of the transistor have different currents (IDS1,IDS2) due to the Hall effect, and so the drain-current difference (IH) can be used as a sensing signal. Traps exist at both lateral si/sio2 interfaces of the device.

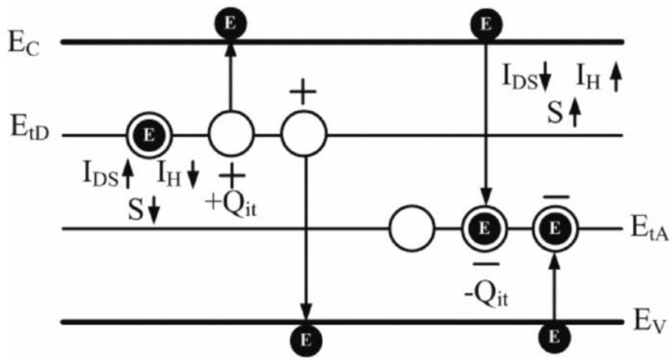

Figure 2. Energy band diagram with acceptor traps and donor traps. The electron exchange between the traps and the conduction band (EC) or valence band (EV) are shown in the diagram. The energy levels of acceptor (EtA) and donor traps (EtD) lie in the energy gap. The acceptor traps capture electrons to become negatively charged while the donor traps emit electrons to become positively charged.

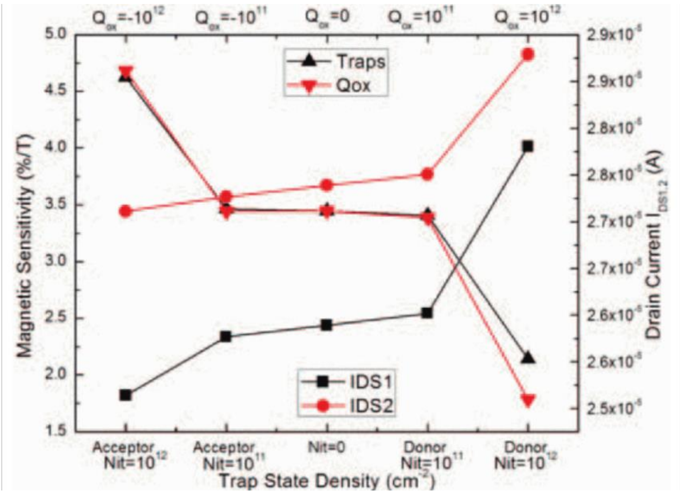

Figure 3. Effects of interface trap (triangles) and oxide charge (inverted triangles) on magnetic sensitivity (=IH/((IDS1+IDS2)Bz)) for two values of density. The two drain currents IDS1 (squares) and IDS2 (circles) as a function of trap density are also shown.

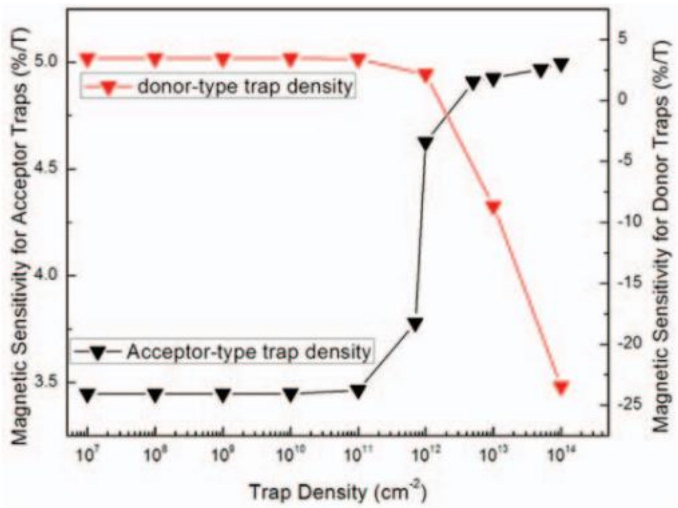

Figure 4. Magnetic sensitivity versus density of acceptor and donor traps.

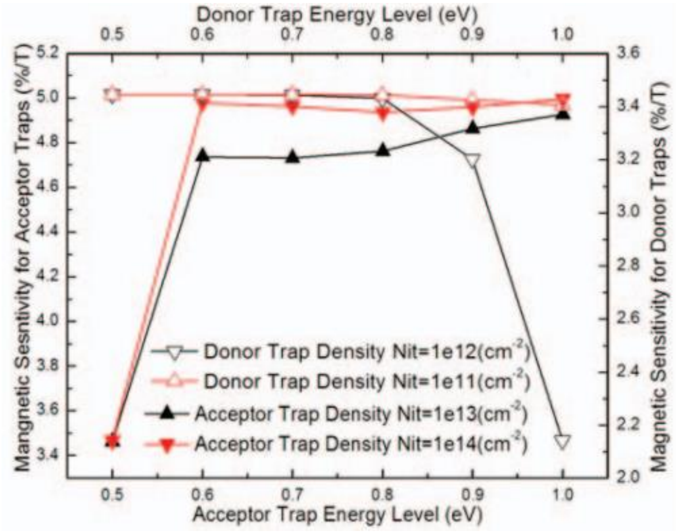

Figure 5. Magnetic sensitivity as a function of trap energy.

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