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Separated Drift Field Magnetotransistor with the p^+ Ring around the Emitter

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A novel magnetotransistor using a separated drift field with a p^+ ring around the emitter has been designed and fabricated. The operating principle of the proposed magnetic field sensor is based on the emitter injection modulation. The p^+ ring around the n-type emitter confines drifted electrons in the emitter and hence the induced Hall voltage in the emitter is increased. The measured relative sensitivity of the separated drift field magnetotransistor with the p^+ ring is about 140 times larger than that of the conventional device without the ring.

1. INTRODUCTION

The magnetotransistor may be one of the most promising devices as a magnetic sensor due to its high sensitivity and process compatibility with the silicon planar technology[1)]. Carrier deflection and emitter injection modulation have been proposed as the operating principle of the magnetotransistor[2,3)]. When a magnetotransistor is operated by the emitter injection modulation, much improvement in the sensitivity can be expected. But it has been reported that emitter injection modulation has minor effect on the operation of the magnetotransistor in the general structure[4)].

We fabricated a separated drift field magnetotransistor with the p^+ ring around the emitter, which implements emitter injection modulation as the operating principle and analyzed its characteristics.

2. STRUCTURE AND CONCEPT

The fabricated separated drift field magnetotransistor is an npn bipolar transistor with dual collectors which has a symmetrical structure as shown in Fig. 1.

Lateral voltage is applied through the two emitter contacts and identical lateral voltage is applied through the base contacts in order to maintain a uniform emitter-base forward junction bias along the emitter edges. When magnetic field is applied, electrons drifted in the emitter by the lateral field are deflected to one side by the Lorentz force and Hall voltage is induced across the emitter. The induced Hall voltage modulates the left and right emitter-base bias which results in the collector current difference.

The emitter is surrounded by the p^+ ring which is intended to increase the relative sensitivity by the enhancement of the Hall voltage across the emitter. Without the p^+ ring, carriers do not accumulate sufficiently so that only a small magnitude of Hall voltage is induced. However, by employing the highly doped p^+ layer the potential barrier between the

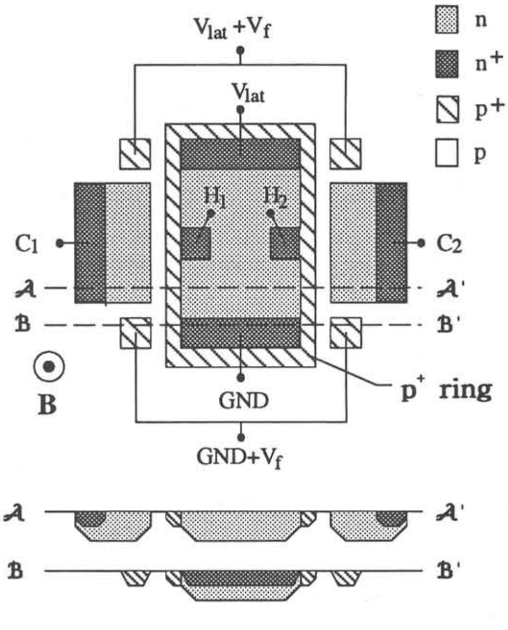

Fig. 1. Structure of the fabricated separated drift field magnetotransistor with the p^+ ring around the emitter.

emitter and the base is increased. This causes the carriers deflected by the Lorentz force to accumulate at the emitter-base junction on the emitter side which enlarges the induced Hall voltage across the emitter. As a result, the relative sensitivity, which is directly dependent on the induced Hall voltage, is increased significantly.

Fig. 2 shows the measured Hall voltage with the variation of the lateral voltage when magnetic field of 0.3 tesla is applied. We can see that Hall voltage of upto 60mV is induced which is the effect of the p^+ ring. Also, it can be noticed that the induced Hall voltage varies linearly with the lateral voltage which corroborates the fact that the emitter region acts as a Hall plate.

3. EXPERIMENT AND DISCUSSION

The separated drift field magnetotransistor with the p^+ ring has been fabricated by employing the standard CMOS process. We used a permanent magnet of 0.3 tesla for generating the magnetic field and HP4145B for driving and measuring the magnetotransistor.

Fig. 3 shows the collector current difference with the variation of the emitter-base bias. The collector current in the absence of magnetic field can be expressed as

$$I_c = I_s\ (e^{qV_f / kT} - 1) \qquad (1)$$

where I_s denotes the saturation current and V_f the forward bias. When magnetic field is applied, the forward bias at one emitter-base junction increases by $V_H/2$ while the forward bias at the other junction decreases by the same amount. Accordingly, the collector current difference can be expressed as follows.

$$\Delta Ic = 0.5 \cdot I_s \cdot\ [(e^{q(V_f + V_H/2)/kT} - 1) - (e^{q(V_f - V_H/2)/kT} - 1)]$$

$$= I_s\ (e^{qV_f / kT} - 1)\ \sinh(qV_H / 2kT) \qquad (2)$$

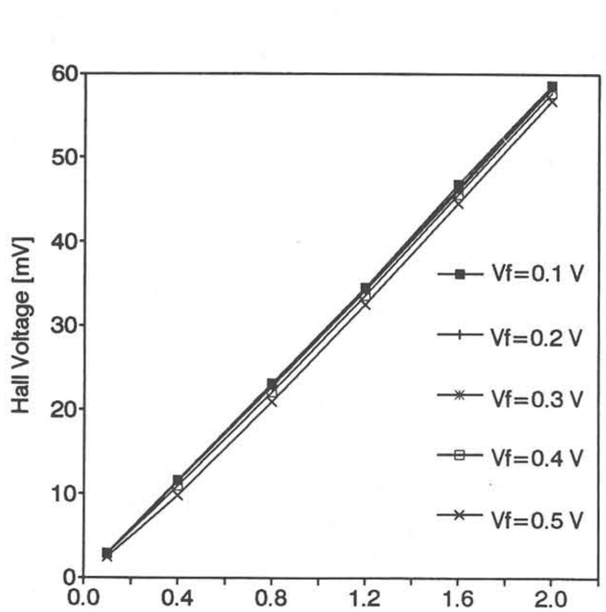

Fig. 2. Induced Hall voltage with the variation of the lateral voltage. (B=0.3 tesla, V_c=7 volts)

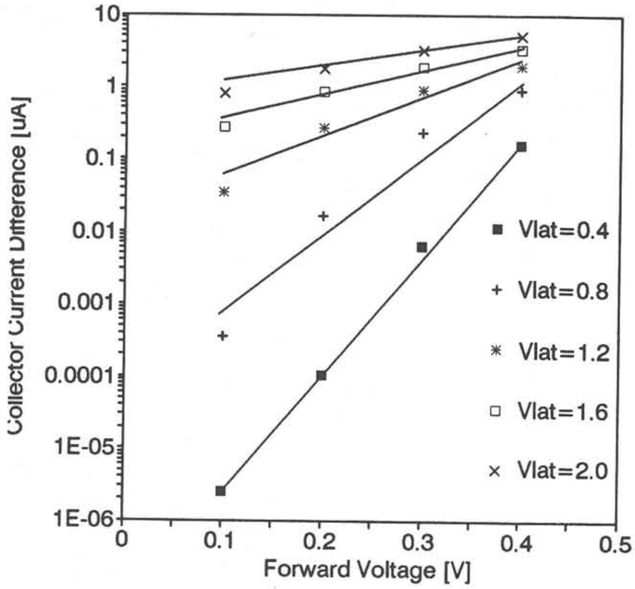

Fig. 3. Collector current difference with the variation of the forward bias. (B=0.3 tesla, V_c=7 volts)

According to this equation, the collector current difference increases exponentially with the increase of forward bias. Fig. 3 shows that the collector current difference varies exponentially with forward bias which is an evidence for the emitter injection modulation to be the operating principle of the separated drift field magnetotransistor and not carrier deflection.

Fig. 4 shows that the collector current difference increases with the increase of the lateral voltage. This means that imbalance in the collector current is caused by the drift of carriers due to the lateral field in the emitter. By optimizing the emitter structure for the applicable lateral voltage, much larger collector current difference can be obtained.

The measured relative sensitivities of the device is shown in Fig. 5 as a function of the lateral voltage. The relative sensitivity S_r can be expressed as

$$S_r = \frac{\Delta I_c(B)}{I_c(0) \cdot B} = \frac{\sinh(qV_H / 2kT)}{B} \qquad (3)$$

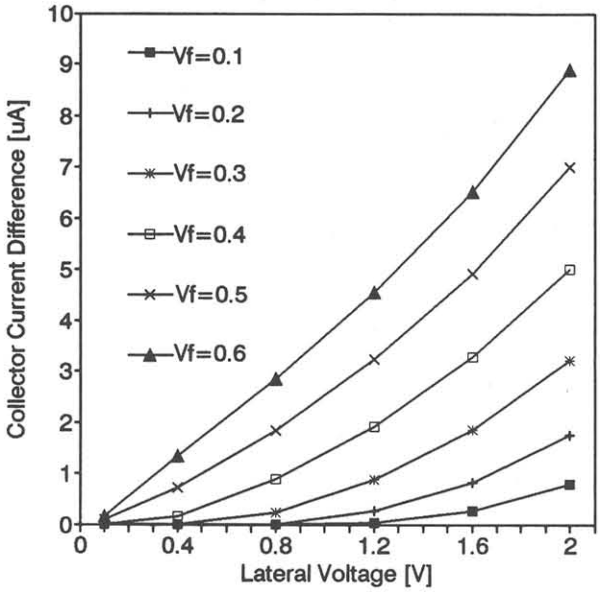

Fig. 4. Collector current difference with the variation of the lateral voltage. (B=0.3 tesla, V_c=7 volts)

where $\Delta I_c(B)$ denotes the collector current difference in the presence of magnetic field and $I_c(0)$ the total collector current in the absence of magnetic field. When the forward bias is fixed, the total collector current does not change while the collector current difference increases with the increase of the lateral voltage, which results in the increase of the relative sensitivity as shown in Fig. 5.

In Fig. 6 the relative sensitivity of the magnetotransistor with the p^+ ring and the one without the ring operated at forward bias of 0.2 V are compared. We can observe that the relative sensitivity has improved drastically from 0.7 to 99.0 %/T. This large increase is due to the employment of the p^+ ring which confines carriers and hence enhances the induced Hall voltage across the emitter. This experimental result validates the successful employment of the p^+ ring.

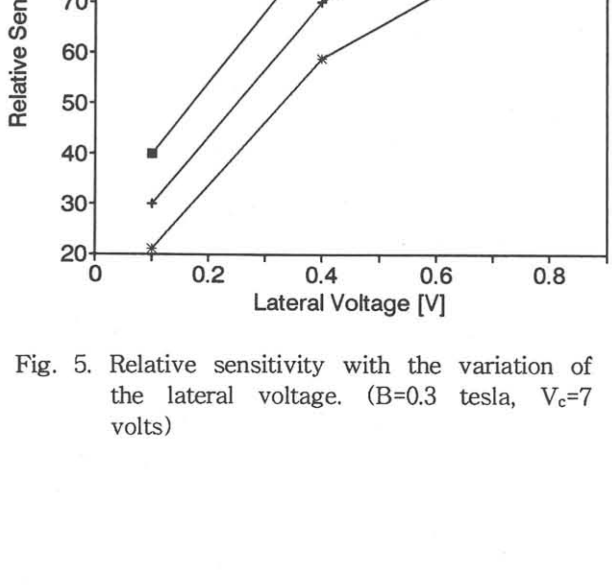

Fig. 5. Relative sensitivity with the variation of the lateral voltage. (B=0.3 tesla, V_c=7 volts)

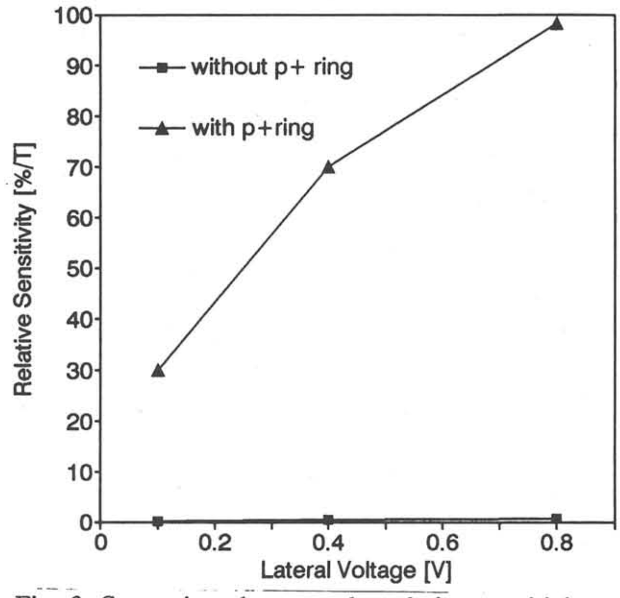

Fig. 6. Comparison between the relative sensitivity of the separated drift field magneto-transistor with the p^+ ring and the one without the ring. (V_f=0.2 volts, B=0.3 tesla, V_c=7 volts)

4. CONCLUSION

We fabricated a separated drift field magneto-transistor with the p^+ ring around the emitter which is operated by the emitter injection modulation. By separating the drift field from the carrier injection the effect of the emitter injection modulation can be largely increased. The p^+ ring around the emitter increases the potential barrier between the emitter and the base so that the value of the induced Hall voltage is enlarged. As a result the relative sensitivity is increased tremendously. The measured relative sensitivity of the magnetotransistor with the p^+ ring is about 140 times larger than the one without the ring, which demonstrates the important contribution of the p^+ ring on the device performance.

5. REFERENCES

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