A Lateral-Type Field Emission Based Magnetic Sensor Fabricated with Electron Beam Lithography for Measuring Electric Current

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A deflected edge emission field effect transistor (DEEFET), a hybrid solid-state and vacuum microelectronics device, was constructed to measure magnetic fields, which will subsequently be transformed to provide current readings. Compared with conventional semiconductor magnetic sensors such as Hall devices and magnetoresistors, the DEEFET device has several advantages: higher magnetic sensitivity, greater tolerance to high temperature and thermal radiation environments, and wideband frequency response.

Fig. 1 shows SEM image of the fabricated device. Five metal electrodes consisting of an extremely sharp emitter (gold), a pair of gates, and a pair of split anodes, were employed. When a positive bias is applied to the anode and negative bias to the sharp emitter, a high electric field is induced around the tip due to the field enhancement factor. Electrons are emitted from the tip and then collected to the anode. When an external magnetic field is not present, equivalent current is received at both symmetrically arranged anodes. However, when an external magnetic field *B* is applied perpendicular to this device, the emitted electrons deviate from the initial trajectory due to the Lorentz force, which causes imbalance between the currents received by the two neighboring anodes. Therefore, we can detect the density and direction of the external magnetic field by measuring the anode current imbalance.

Electron beam lithography (EBL) was used to make a sharp tip. The tip radius is approximately 250Å and the aspect ratio of the tip height to the tip apex width is about 600:1. The distances between the emitter and the gate, and the emitter and the anode are a few microns. The emission current was measured as a function of the anode voltage at a pressure of less than 10^{-9} Torr. The emitter was grounded and the anode currents were measured, when a magnetic field *B* is not present. Clear field emission currents were observed around an anode bias of 30V. The currents to Anode 1 and Anode 2 were almost identical.

To observe the magnetic sensitivity, forward and reverse magnetic fields of 0.5 Tesla were applied. First, a forward magnetic field *B* was applied from top to bottom. The current at Anode 2 was increased and the Anode 1 current was decreased because the Lorentz force causes the emitted electrons to deviate toward Anode 2. A clear current distinction between the two anodes is observed (Fig. 2). For V_a=150V, the current imbalance is calculated to be 0.364μA. Additionally, a reverse magnetic field *B* was applied from bottom to top. Since the emitted electrons are deflected toward Anode 1 and away from Anode 2, the current at Anode 1 was increased.

The magnetic sensitivity *S* is defined as [1]

$$S = \left| \frac{\Delta I_a}{I_a} \cdot \frac{1}{B} \right| \qquad (1)$$

where ΔI_a is the anode current difference between Anode 1 and Anode 2 (=$|I_{a2} - I_{a1}|$). The calculated magnetic sensitivity is 78%/Tesla for a forward magnetic field of 0.5 Tesla and 37%/Tesla for the reverse magnetic field. These magnetic sensitivities are up to 5 or 6 times higher than those from conventional solid-state magnetic sensors.[2]

After fixing the gate potential at a constant voltage, the emission current was measured at both anodes. At the condition where a constant gate bias of 50V was supplied, a forward or a reverse magnetic field *B* of 0.5 Tesla was applied. From the results obtained when a forward or a reverse magnetic field *B* was present, the current imbalance ΔI_a and the magnetic sensitivity *S* were measured, and presented in Table I. As the gate bias of 50V was applied, ΔI_a was slightly decreased because the positive gate potential spreads the emitted electrons outward. That is, the gate bias does improve the turn-on voltage and emission current, but it may decrease the magnetic sensitivity.

Reference

[1] S. Selberherr, *Computational Microelectronics*, Springer Wien New York, 1999.
[2] Y. Sugiyama, *J. Vac. Sci. Technol.*, B 13(3), p. 1075, 1995.

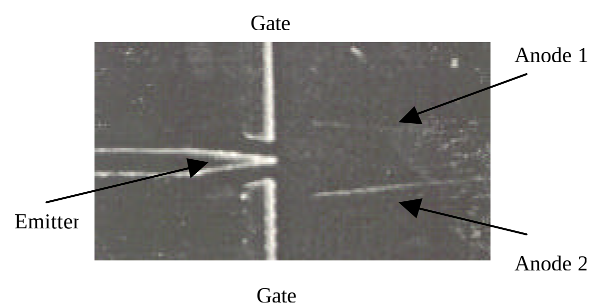

Fig. 1. SEM images of the fabricated device.

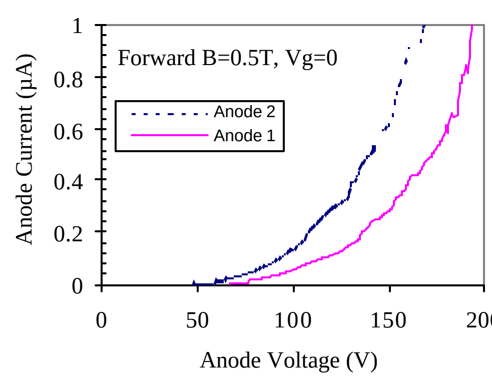

Fig. 2. Device I-V characteristics when a forward magnetic field of 0.5T is present.

TABLE I
Deviation results of the fabricated device when forward and reverse magnetic fields are present at a constant gate bias of 50V (B=0.5T, V_a=120V)

	Forward *B*		Reverse *B*	
	V_g=0V	V_g=50V	V_g=0V	V_g=50V
Total I_a	~0.8μA	~0.8μA	~0.8μA	~0.8μA
ΔI_a	0.31μA	0.212μA	0.138μA	0.095μA
$\Delta I_a/I_a$	39%	26%	17%	12%
Sensitivity	75%/T	53%/T	35%/T	26%/T