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High Sensitivity Hall-Effect Sensor on the AlGaN/GaN Fin-HEMT Structure

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Abstract

Hall-effect sensors are widely used for proximity sensing, control and condition monitoring purposes. Current technology makes use of the high density 2DEG formed in InGaAs and InAsSb materials to achieve high sensitivity. However, these semiconductors have low bandgap energies (between 0.4 – 1.4 eV) which make them unsuitable for higher temperature operation of more than 150°C. This paper proposes a Hall-effect sensor configuration on AlGaN/GaN Fin-HEMT structure which gives a high sensitivity Hall voltage. It is suitable for system integration and high-temperature applications.

1. Introduction

The magnetic sensors are used in various applications, such as in the oil and gas exploration systems, in the automotive and aircraft engines, and in the scanning Hall probe microscopy. In such environments, the magnetic sensors should be tolerant to the high temperature and of a good sensitivity and reliability. Micro Hall effect sensors are commonly fabricated using narrow band-gap semiconductors such as InAsSb and GaAs. In general, the sensed output Hall voltage is dependent on the carrier mobility and Hall coefficient RH (Ω/G) of the material. If the mobility of the material is larger, the Hall sensor will be more sensitive. Accordingly, a III-V family compound semiconductor with large mobility is generally used as the material for the Hall element. They are good to be made with integrated circuit for on-chip sensor integration, and they provide fairly good sensitivities with the typical Hall coefficients above 0.2 Ω/G (for InAsSb) and 0.05 Ω/G (for GaAs). However, these Hall sensors have limited temperature range to operate below 150°C. Beyond it, the sensitivity starts to degrade heavily and become unsuitable for sensing applications.

AlGaN/GaN high electron mobility transistors (HEMTs) have recently been widely explored. The GaN device is capable to operate at high temperature, theoretically to reach above 800°C. With the high spontaneous and piezoelectric polarization charges in AlGaN/GaN heterostructure, the net positive polarization charges at AlGaN/GaN interface induce free electrons to accumulate and form the 2-D electron gas (2DEG). The induced 2D electron density over 10^{13} cm^{-2} can be achieved without external doping. Good electron mobility over 2000 $cm^2/V\cdot s$ has been realised with little scattering in the undoped AlGaN/GaN heterostructure.

Recently AlGaN/GaN heterostructure based micro Hall-effect sensors have been reported [1-6]. The large wide band-gap of GaN and AlGaN (>3.4 eV) leads to lower intrinsic carrier density and enables the devices to operate in higher temperatures stably up to 300 °C [1,2] with good magnetic field linearity and low thermal drift. On the other hand, the large band-gap also provides higher radiation-tolerant capability. In recent work, the AlGaN/GaN micro Hall-effect sensors have exhibited robust and high sensitivity properties at up to 400 °C and under irradiation of 380 keV protons [3]. For the optimised $Al_{0.3}Ga_{0.7}N$/GaN heterostructure HEMT for Hall sensor application reported in [1], the room temperature "supply-current-related sensitivity" (SCRS) of 55 V/AT and low temperature cross sensitivity of 103 ppm/°C up to 300 °C were obtained by the fabricated square-shaped Hall-effect sensor. For the long channel AlGaN/AlN/GaN heterostructures reported in [2], Hall-effect measurements were conducted up to 300 °C. These reported devices can be used at high temperature with a magnetic sensitivity close to 60 V/AT and a limited thermal drift. The best sample in [2] exhibits average value of the thermal drift is −7 ppm/°C between liquid helium temperature and 300 °C.

Having said that, the major shortcoming of the AlGaN/GaN micro Hall-effect sensors is that they have far lower SCRS sensitivity in comparison to AlInSb/InAsSb/AlInSb based counterpart, which has a higher sensitivity close to 900 V/AT. The SCRS values of AlGaN/GaN and AlInSb/InAsSb/AlInSb micro Hall sensors are compared in [3, 5]. In the comparison, the AlInSb/InAsSb/AlInSb Hall device showed a higher sensitivity of 870 V/AT at room temperatures. However, the operations of the AlGaN/GaN micro Hall sensors were stable up to 400 °C with a sensitivity of below 80 V/AT.

In this paper, we propose the formation of Hall-effect sensor on the AlGaN/GaN Fin-HEMT structure. The Fin structure can largely enhance the current density flowing through the 2DEG region, thus enhance the Hall voltage sensitivity.

2. The Device Structure and Simulation

The 3D schematic of the fin-gate MIS-HEMT structure with Hall-effect sensor is shown in Fig. 1 (a). The X-Y (width-height) cross-sectional schematic is shown in Fig. 1(b). The HEMT threshold voltage is determined by its fin width with relaxation effect, dielectric permittivity and thickness. 3D simulations by TCAD Sentaurus tool are carried out to indicate the variation of threshold voltage as a function of fin width and Al_2O_3 thickness, as shown in Fig. 2 [7]. It is concluded that a positive threshold voltage can be obtained for sensor current control by narrowing the fin width to below 40 nm in the case that Al_2O_3 thickness is 10 nm.

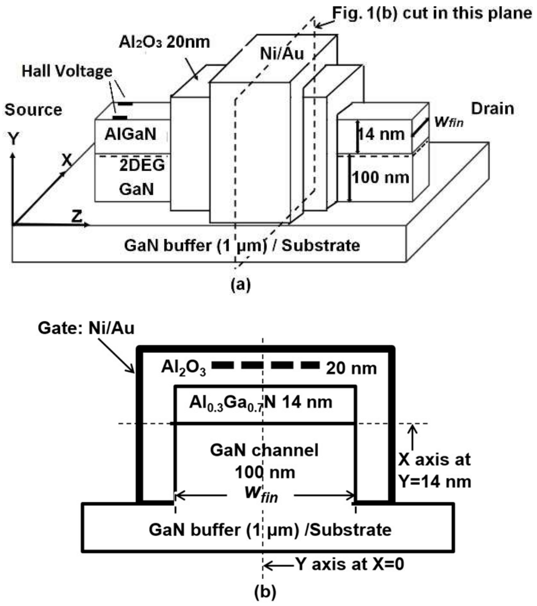

Fig. 1. (a) 3D schematic of the MIS-FinFET structure with Hall sensor; (b) X-Y cross-sectional schematic of the structure.

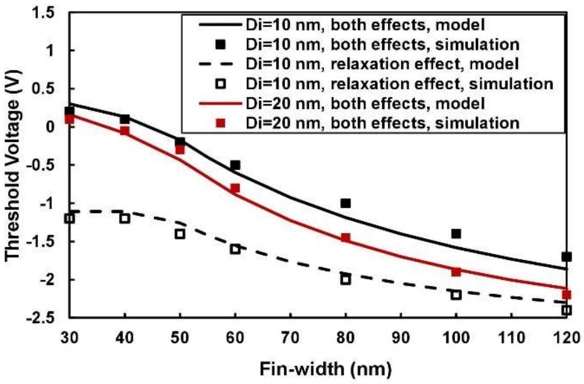

Fig. 2. Verification of the threshold voltage model with TCAD simulation at different values of fin width and dielectric thickness.

Here we integrate the Hall-effect sensor on the fin region with the consideration of both for sensor control and integration, and for higher Hall voltage sensitivity. Fig.3 gives the analysis on the current distribution within and outside the 2DEG region when reducing the fin width. It is seen that more than 90% of the drain current remains kept within the 2DEG region even when the fin width is reduced down to 30nm.

Fig.4 gives the Hall voltage output at different drain current, namely 1μA, 2μA and 4μA, and fin width at flux density of 0.1T. It is seen that the Hall voltage is raised when the fin width is reduced down below 100 nm. For the case of 30 nm at 4μA drain current, it has the maximum Hall voltage of 4.4 V in comparison to the background, the enhancement in Hall voltage is more than 50 times.

The Fin HEMT device fabrication is currently undergoing and we expect the fabrication to complete shortly and will report the measurement data later at the conference.

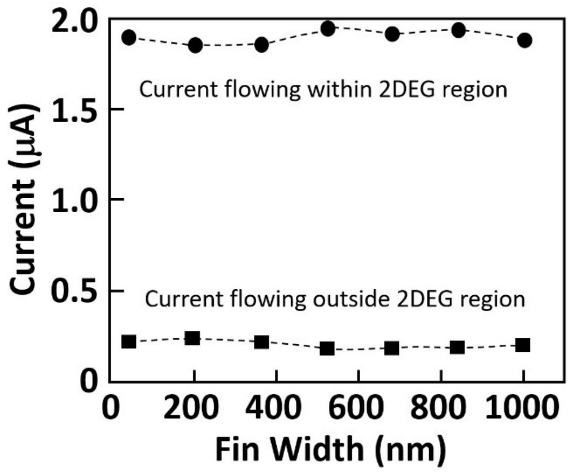

Fig. 3. Current distribution in the fin region between that flowing within the 2DEG region and that flowing outside the 2DEG region in the GaN.

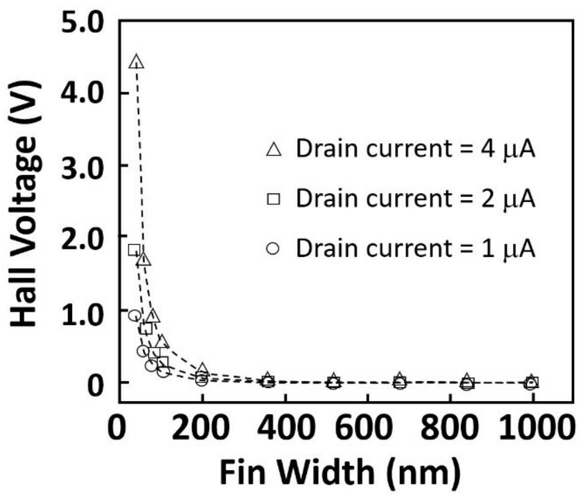

Fig. 4. The output Hall voltage at different drain current and fin width at B = 0.1T. The Hall voltage is enhanced when the fin width is reduced below 100nm.

3. Conclusions

This paper proposed an integrated Hall-effect sensor on AlGaN/GaN fin-HEMT structure for a higher sensitivity and better temperature operation range. Simulations indicated that the Hall voltage sensitivity can be enhanced more than 50 times.

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