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A new drain insulation design in GaAs SD-MAGFET

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A new design of a split-drain MAGFET type magnetic sensor based on GaAs MESFET device with a sandwich-like drain configuration has been investigated. An excellent performance of the sensor, namely its high sensitivity and spatial resolution to magnetic field could be obtained as a result of an extremely short (200 nm) distance between the transistor drains realized using a unique epitaxial layer structure. A proper sequence of the AlGaAs/GaAs/AlAs/GaAs epitaxial layers grown by MOCVD technique followed by selective etching process has been proposed and realized. Structural parameters of the layers were studied. Electrical performance of the insulated drain structure was evaluated by measurements of the leakage current that was less than 10 nA for 2 V drain voltage bias difference.

Key words*: MAGFET; GaAs MESFET; epitaxial growth*

1. Introduction

Split-drain magnetic field sensitive field-effect-transistors (SD-MAGFET) are widely known magnetic field sensors [1]. Usually they are based on Si MOSFET devices with two or three split-drain contacts separated vertically, i.e., by an insulating layer perpendicular to the sensor surface. MAGFET sensors are also fabricated in GaAs technology and are based on HEMT type or resistor type [2] structures with high mobility 2DEG (2-dimensional electron gas).

Independently of the used technology, SD MAGFET sensors are based on the Hall effect and the resulting current difference between the two drains in the presence of a magnetic field. The sensitivity of a two-drain device is defined as

$$S = \frac{I_{d2} - I_{d1}}{\left(I_{d2} + I_{d1}\right)|B|}$$

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where $(I_{d2} - I_{d1})$ is the measured output signal, i.e., the drain current imbalance, directly proportional to the carrier mobility and the channel length. On the other hand, the differential current signal is inversely proportional to the separation distance between the drains. Locating the drain regions as close to each other as possible would increase the sensitivity as well as spatial resolution of a magnetic field, especially for small cross section area MAGFETs.

In this view, a new design approach for GaAs based MAGFET, where the drains are located one on top of the other (horizontally split-drains) separated by an electrically insulating layer, has been proposed [3]. The device structure is made of several epitaxial layers and subsequently etched mesas. A unique performance advantage of the device is its high sensitivity and spatial resolution due to extremely short distance between the drains, of the order of 200 nm (thickness of the epitaxial layer). Such a small drain separation is obtained using a GaAs/AlAs epitaxial structure that gives an efficient carrier collection and at the same time provides electrical insulation between the drain regions. A schematic view of the proposed split-drain MAGFET structure, in this particular case with two gate electrodes for a better current control, is shown in Fig. 1.

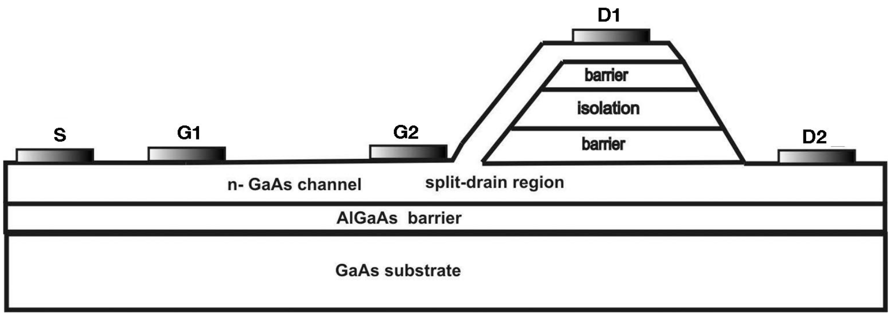

Fig. 1. Schematic view of a MAGFET structure (drawing not to scale)

In this work, a proper growth of the epitaxial layer sequence and subsequent layer selective etching processes have been investigated. The study is focused on the drain insulation region. The electrical performance of the structure is characterized by capacitance–voltage and current–voltage measurements.

2. Fabrication

Epitaxial structures of MAGFET sensors were grown by atmospheric pressure metal organic vapour phase epitaxy (APMOVPE) with an AIX200 R&D horizontal reactor. The following epilayers were grown on (100) – oriented semi-insulating (SI) GaAs substrate (layer thickness and carrier concentration are given):

- Undoped (UD) buffer heterostucture: GaAs (0.5 μm)/ $Al_{0.3}Ga_{0.7}As$ (0.5 μm).
- Two silicon-doped GaAs epilayers: n-GaAs (0.2 μm, $n \approx 2\times10^{17}$ cm^{-3})–n$^+$GaAs (0.2 μm, $n \approx 3\times10^{18}$ cm^{-3}), created a channel and a contact layer (drain D2) of the MAGFET.

• A sequence of three layers formed an insulation between two drains:
– a zinc-doped p^+-GaAs layer (20 nm, $p \approx 1\times10^{19}$ cm^{-3}),
– an undoped (UD) AlAs (0.2 μm),
– a zinc-doped p^+-GaAs layer (20 nm, $p \approx 1\times10^{19}$ cm^{-3}).
• Two silicon-doped GaAs epilayers: n-GaAs (0.1 μm, $n \approx 2\times10^{17}$ cm^{-3})–n^+GaAs (0.1 μm, $n \approx 3\times10^{18}$ cm^{-3}), created a channel and a contact layer (drain D1) of the MAGFET.

The growth process was carried out at 670 °C except of the AlAs epilayer grown at a higher temperature (760 °C) to improve its structural properties. Trimethylgallium (TMGa), trimethylaluminium (TMAl), arsine (AsH_3: 10% mixture in H_2), diethylzinc (DEZn) and silan (SiH_4: 20 ppm mixture in H_2) were used as the growth and dopant precursors. High purity hydrogen was employed as a carrier gas.

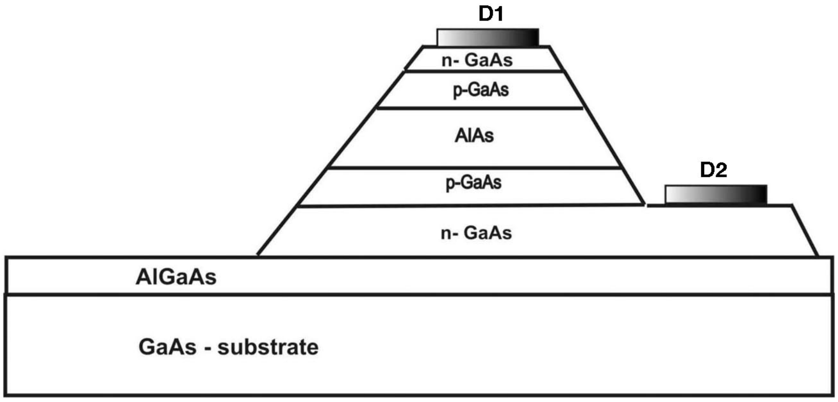

Fig. 2. The investigated insulated drain structure

Mesa type delineations of the structures were performed by several selective wet chemical etching steps in buffered hydrofluoric acid and citric acid, for AlAs and GaAs layers, respectively. The total height of the etched mesas was 0.9 μm and the diameter of the mesa structure was 150 μm. Ohmic contacts were obtained in a standard procedure using AuGe/Ni/Au metalization and alloying at 450 °C. A complete test structure is shown in Fig. 2.

3. Structural and electrical properties

Structural and electrical properties of the obtained MAGFET heterostructures were estimated using a Philips high resolution materials research diffractometer (HRMRD) with a four-crystal Bartels monochromator, a Bons/Hart analyser and a Bio-Rad PN 4300 electrochemical capacitance–voltage (EC–V) profiler. The rocking curves measurements (Fig. 3) allowed evaluation of the compositions and thicknesses of the epilayers. The angle distance between the reflexes from the GaAs substrate and from AlGaAs (or AlAs) gives information about the aluminium content in the layer. The value $x = 0.34$ was estimated for the $Al_xGa_{1-x}As$ buffer. The presence of the Pendellösung fringes indicates good structural quality of the structure and gives information about the thickness of all epilayers except for GaAs buffer.

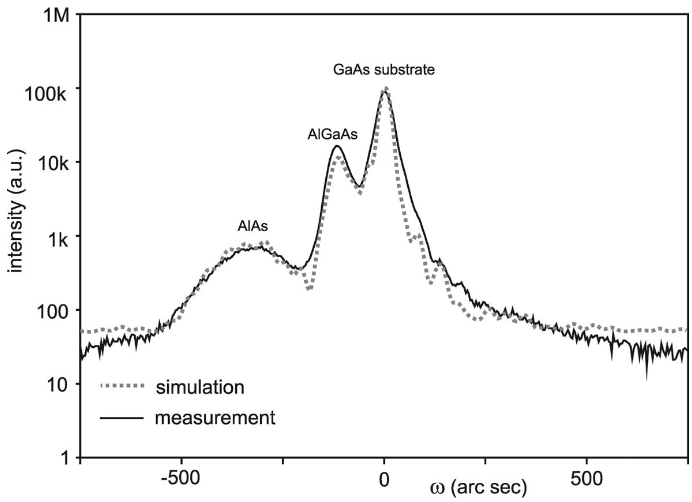

Fig. 3. Rocking curves of the MAGFET sensor structure for the (004) reflection (line – measurement, dots – simulation)

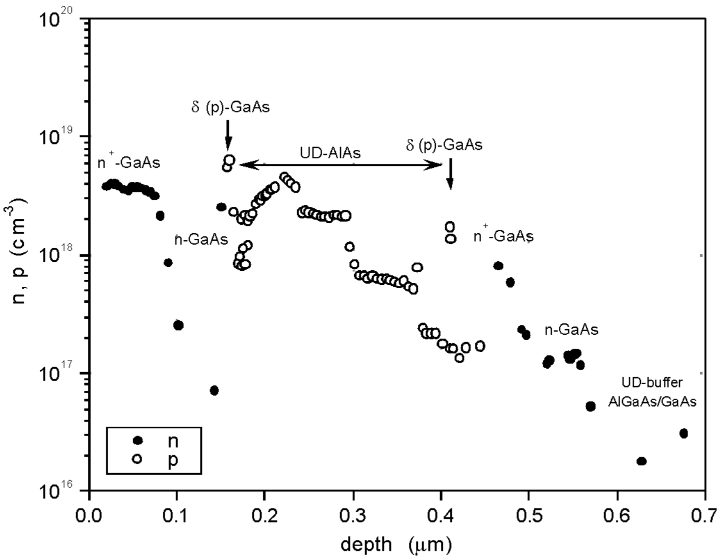

Fig. 4. EC-V profile of the MAGFET sensor structure

Carrier concentration in the doped layers of the MAGFET was determined by EC–V measurements. The method uses a capacitance–voltage analysis of a reverse biased electrolyte–semiconductor Schottky junction. The obtained EC–V profile is shown in Fig. 4. The carrier concentration in every layer was readable. Determination of the carrier concentration in the undoped AlAs layer was difficult due to the etching problems.

4. Current-voltage characteristics

An important feature of the split-drain sensor is the electrical insulation between the drains. The current from the transistor source is distributed into two drain currents that should be of equal value in the absence of a magnetic field. A balance of the drain currents could also be obtained by changing the voltage bias of one drain with respect to the other. To accomplish the equilibrium condition, the drain regions should be electrically insulated. Current–voltage characteristics of the structure have been recorded sensing the current between drains and between source and drains. A typical characteristic of the voltage dependent leakage current in the isolated mesa is presented in Fig. 5.

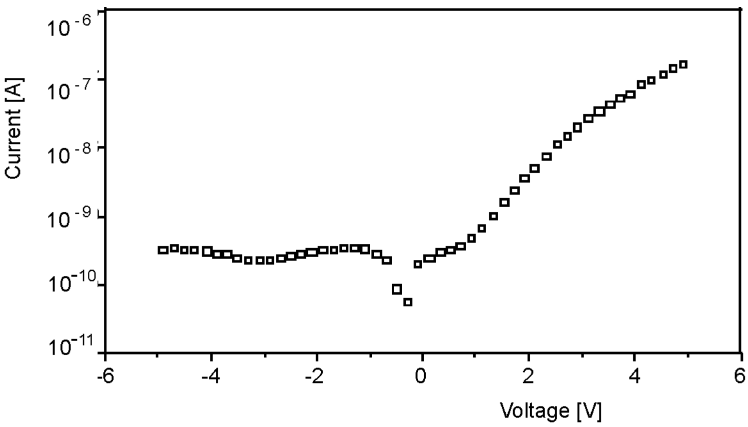

Fig. 5. Current-voltage dependence of the drain insulation structure

Up to 2 V of voltage bias difference between the drains, the current is not larger then 10 nA and a noticeable current rise-up is observed for the bias larger then 3 V. However, from the simulation results not included here, it appears that equilibrium condition for the drain currents may require drain bias difference of just about 1V. This would cause not more than 1 nA of the parasitic current between the drain regions.

5. Conclusions

A novel concept of the drain separation design in a split-drain GaAs MAGFET sensor based on epitaxial layer growth has been tested. A proper choice of GaAs/AlAs/GaAs epitaxial sequence provided good electrical insulation between drain regions. The measured leakage current between drain regions was in the range of nA for up to 2 V drain voltage bias difference. This technique may increase magnetic field sensitivity of the MAGFET sensors.

Acknowledgements

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