Angular Dependence of InP High Electron Mobility Transistors for Cryogenic Low Noise Amplifiers under a magnetic field

Citation for the original published paper (version of record):
Harrysson Rodrigues, I., Niepce, D., Moschetti, G. et al (2019)
Angular Dependence of InP High Electron Mobility Transistors for Cryogenic Low Noise Amplifiers under a magnetic field
IIS UTokyo SYMPOSIUM No.100

(article starts on next page)

Angular Dependence of InP High Electron Mobility Transistors for Cryogenic Low Noise Amplifiers under a magnetic field

I. H. Rodrigues*[1], D. Niepce[1], G. Moschetti[2], A. Pourkabirian[2], J. Schleeh[2], T. Bauch[1], J.Grahn[1]

[1]*Department of Microtechnology and Nanoscience – MC2, Chalmers University of Technology, SE-41296 Gothenburg, Sweden*

[2]*Low Noise Factory AB, Nellickevägen 22, Gothenburg, SE-41663, Sweden*

* isabelr@chalmers.se

This work addresses the angular dependence of DC properties in 100nm InP HEMT devices under the influence of applied static magnetic field at 2 K. When kept at an angle 90º towards a magnetic field of 14 T, the maximum output drain current I_{ds} was reduced more than 99 %. A rotation sweep of the transistor revealed a strong angular and B-field dependence on I_{ds}. This was correlated with a reduction in dc transconductance and increase in on-resistance of the transistor. The RF properties of the transistor were tested by measuring an 0.3-14 GHz InP HEMT MMIC low-noise amplifier (LNA) at 2 K kept at an angle 90º towards a magnetic field up to 10 T. The gain and noise temperature were strongly decreased and increased, respectively, already below 1 T. The results show that precise alignment of the cryogenic InP HEMT LNA is crucial in a magnetic field. Even a slight mis-orientation of a few degrees leads to a strong degradation of the gain and noise temperature.

Keywords— InP HEMT; low noise amplifier; cryogenic; angular dependence; magnetic field;

The InP HEMT was recently reported to be strongly affected when aligned perpendicular (or 90º)-with respect to a magnetic field up to 2 T [1]. This has implications on the alignment of cryogenic InP HEMT low-noise amplifiers (LNAs) under strong magnetic fields. Such ultra-sensitive microwave receivers are used in detector experiments of dark matter [2] and mass spectrometry [3]. A potential application is MRI where cryogenic LNAs can provide increased sensitivity [4]. Previous reports on the cryogenic LNA ha only reported on 0 or 90º orientation versus magnetic field [5]. We have here for the first time studied the angular dependence from 0 to 90º of the cryogenic InP HEMT under applied magnetic fields.

In Fig. 1. a schematic illustration of the experiment is shown. All measurements were carried out at an ambient temperature of 2 K. An external magnetic field was applied with an angle θ relative to the two-dimensional electron gas (2DEG) of the device which was a 130 nm In HEMT [6]. Fig. 2. (a)-(c) shows the output drain current I_{ds} at different gate voltages V_{gs} for an applied field of 0, 7 or 14 T. It is clear that the output drain current is drastically reduced with increased field, also illustrated in Fig. 2 (d) using normalized I_{ds} as a function of B. Furthermore, the dc transconductance as a function of magnetic field for different θ showed the same trend; see Fig. 3 (a). The on-resistance R_{on} versus magnetic field strongly increased, also dependent on θ; see Fig. 3 (b). Devices with different gate lengths (60, 100 and 250 nm) and different gate widths (2x10, 2x50 and 2x100 μm) when aligned perpendicular to the applied magnetic fields showed no difference with respect to $I_{ds}(B)$ dependence; see Fig 4. Rotating the sample from θ =0 to 180º revealed a field- and angular dependence; see Fig. 5. The dependence can be expressed using V_{ds}, magnetic field B, θ, a channel resistance R_0 and a fitting parameter A: $I_{ds}(B, \theta) = V_{ds}/R_{xx} = V_{ds}/(R_0 + A(\sin(\theta)B)^2)$. In Fig. 5 the fitting is plotted for $V_{gs} = V_{ds} = 0.4$ V.

The RF properties of the InP HEMT were examined by measuring an 0.3-14 GHz InP HEMT MMIC LNA kept at 2 K in a perpendicular (θ =90º) magnetic field up to 10 T. The InP HEMT in the MMIC LNA was fabricated in the same technology as the device measured in the DC experiments described above. Fig. 6. shows that the gain decreased and the noise strongly increased already up to 1 T of.

This study reveals the importance of precise alignment of the InP HEMT in a magnetic field, to avoid a strong degradation of noise performance of the cryogenic InP HEMTs LNA.

References: [1] I. H. Rodrigues et al., "Magnetic Influence on Cryogenic InP HEMT DC Characteristics," Compond Seiconductor Week, Boston (2018)

[2] C. Hagmann et al., "Results from a search for cosmic axions", Phys. Rev. D 42, 1297 (1990).

[3] R. Mathur, et al., "A Low-Noise Broadband Cryogenic Preamplifier Operated in a High-Field Superconducting Magnet", IEEE Trans. Appl. Superconductivity 18, 1781 (2008).

[4] D. H. Johansen et al., "Cryogenic Preamplifiers for Magnetic Resonance Imaging," IEEE Trans Biomed. Circuits Systems 12, 202 (2018).

[5] E. Daw and R. F. Bradley, "Effect of high magnetic fields on the noise temperature of a heterostructure field-effect transistor low-noise amplifier", J. Appl. Phys. 82, 1925 (1997).

[6] J. Scleeh et al., Characterization and Modeling of Cryogenic Ultralow-Noise InP HEMTs", IEEE Trans. Electron. Dev. 60, 206 (2013).

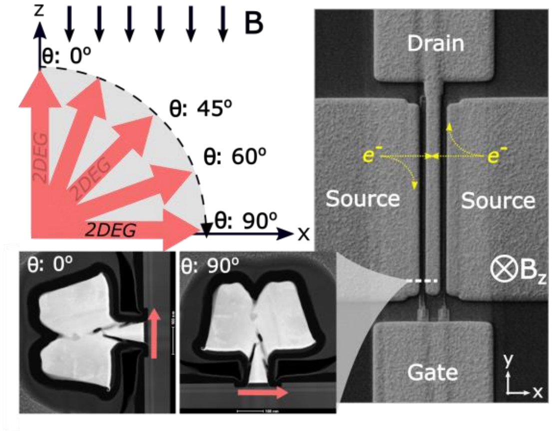

Fig. 1. Schematic image of experiment (top left), where an external magnetic field is applied and the 2DEG in the device, is aligned and rotated with an angle θ relative to the direction of the field. SEM image shown of cross section of gate (bottom left) and top view of transistor (right).

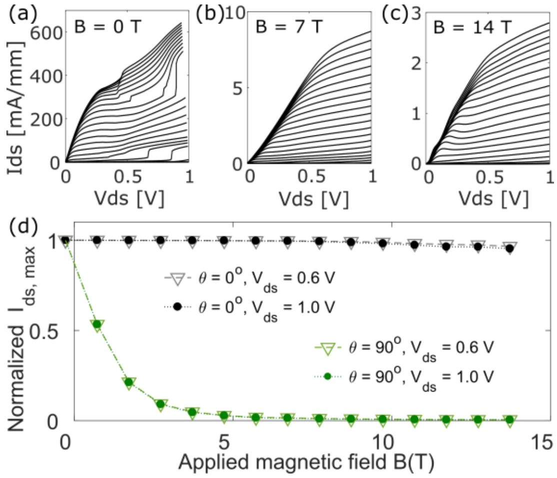

Fig. 2. IV-characteristics with (a) no applied field, (b) an applied field of 7 T and (c) an applied field of 14 T. (d) The normalized output drain current versus field. T=2 K. V_{gs}: -0.4 to 0.4 V, L_g = 100 nm and W_g = 2x50 µm.

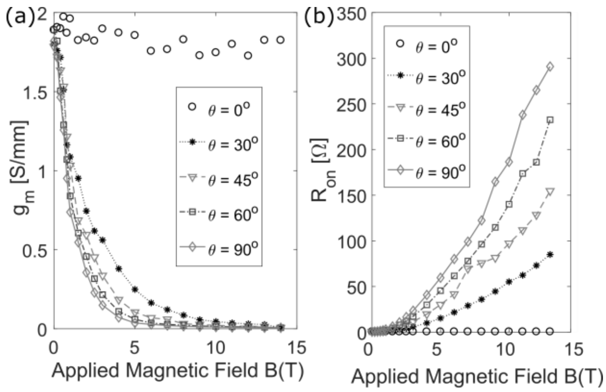

Fig. 3. (a) Transconductance as a function of applied static magnetic field ranging from 0 to 14, applied at various θ: 0 º, 30 º, 45 º, 60 º, 90º . (b) R_{on} versus magnetic field for the same configurations. T=2 K. L_g = 100 nm and W_g = 2x50 µm.

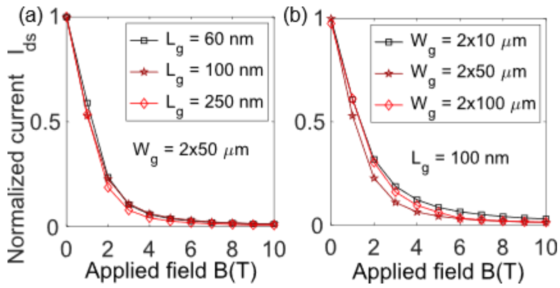

Fig. 4. Normalized I_{ds} for various devices, with (a) different gate length and (b) different gate width, when aligned perpendicular to the applied magnetic fields ranging from 0 to 10 T. A fix V_{gs} and V_{ds} of 0.4 V was applied, in an ambient temperature of 2 K.

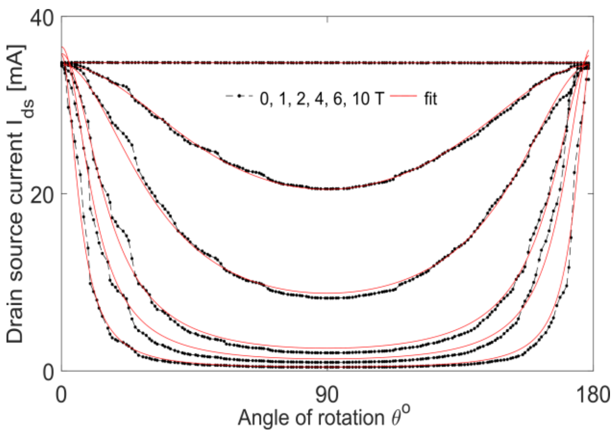

Fig. 5. Fit of rotation sweep. Drain current versus angle of rotation for various applied static magnetic field ranging from 0 to 10 T and biased with V_{gs} and V_{ds} of 0.4 V respectively. T=2 K. Solid line shows a fit of rotation sweep using Eq. (1).

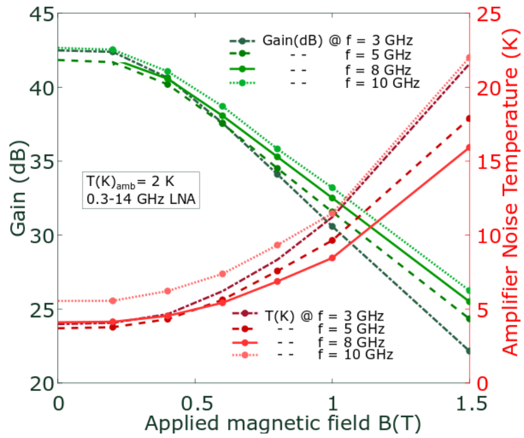

Fig. 6. Experimental set-up for a) gain measurements and b) noise measurements. Gain(dB) (left y-axis) and Noise temperature T(K) (right y-axis) of the cryogenic InP LNA, measured at 2 K, when increasing applied magnetic field from 0 to 1.5 T.