Low-frequency noise behavior of InP-based HEMTs and its connection with phase noise of microwave oscillators

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Abstract.

This paper deals with the investigation of the low-frequency (L.F) noise properties of InP based HEMTs. We have found that a significant part of noise originates from the sample free surface and can be minimized by an appropriate silicon nitride passivation layer. Additional measurements suggest that 1/f noise and lorentzian noise is generated in the AlInAs donor layer of the devices. A comparative study shows that our devices compare well with the state of the art of HEMTs devices in term of excess noise. In order to investigate the correlation between phase noise and L.F noise, both residual and oscillator phase noise measurements were carried out. The obtained results compare well with the state of the art in terms of residual and phase noise performance.

I. Introduction.

HEMTs based on the AlInAs/InGaAs system exhibit the record both in the frequency response [1] and noise figure [2]. In order to put this technology at the industrial level it is necessary to achieve a strong maturity in terms of homogeneous process fabrication and long term stability of electrical performances. One way consists in the deposition on the device surface of a silicon nitride thin film. This passivation technique has shown very attractive results in terms of noise figure and associated gain in the millimeter-wave range [3]. If microwave gain and noise properties have been largely investigated for this type of technology very little data have already been reported on its low-frequency (L.F) noise properties [4,5]. Therefore there is a need concerning this field since it directly impacts on the phase noise of microwave oscillator. Section II deals with a brief description of the samples structures and of their electrical properties. In section III, we report on the results of the low-frequency noise measurements on InP-based HEMT and the possible origin of the excess noise observed in these devices is discussed. These noise data are also compared to the state of the art of the excess noises today observed in HEMT devices. Section IV addresses the results obtained on both residual and oscillator phase noise measurements in order to rule on the connection between oscillator phase noise and L.F noise of active devices. Finally section V is related to the summary of this work and presents the investigations in progress that will be presented at the conference.

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II Device Description

Passivated and unpassivated InAlAs/InGaAs on InP HEMT's featuring 100 and 150 μm gate width and 0.15 μm gate length were fabricated on

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the same MBE-grown layer by IEMN Lille. Devices referred as to A and B were fabricated with a silicon nitride passivation layer and this layer has been etched away for B sample. The fabricated devices featuring 0.15 x 100 μm^2 exhibit a maximum transconductance of 80 mS, a threshold voltage in the 1 volt range. 40 GHz S-parameters measurements show that the passivated and unpassivated devices feature a maximum oscillation frequency of 130 and 250 GHz respectively. This behavior is probably related to a decrease of the inter-electrodes capacitances.
Therefore they are well suited for millimeter-wave circuits design such as millimeter-wave oscillators and it is essential to predict the performances of these oscillators in terms of phase noise. Among the different parameters that will impact on the phase noise, one of the most important is the L.F noise that we will investigate now.

III L.F Noise Measurements

On wafer L.F noise measurements were carried out from 250 Hz to 100 kHz by measuring the input referred noise voltage generator (S_{en}). On fig 1, we have reported the frequency evolution of S_{en} for A and B samples featuring 0.15 x 100 μm^2 gate area at Vds=1.4 V and Vgs=0 V.
The measured spectra indicate firstly that the overall noise results from the superimposition of both 1/f noise and Lorentzian noise which reveal traps in these structures. Secondly we note that the passivated devices exhibit an excess noise level lower than unpassivated ones. This behavior suggests that a part of this excess noise originates from trapping-detrapping effects at the free surface. Consequently passivated devices are best suited for the design of low phase noise oscillators. However these devices feature an L.F noise which appears to be not directly related with surface effects.

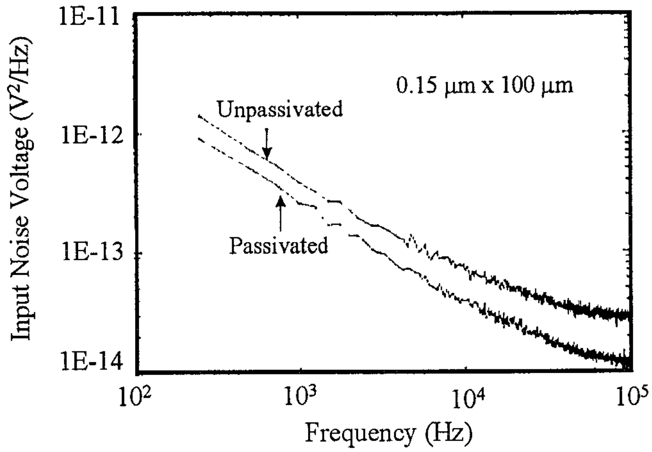

Fig 1 : Input noise voltage versus frequency for A and B samples

To investigate its origin more deeply, we have plotted on Fig.2 the variations versus frequency of the input referred noise voltage measured on the passivated samples (#A) featuring the same gate lengths and two different gate widths. The noise spectra show that the larger gate width device is the noiseless one. This is consistent with noise source located in the bulk of the devices.

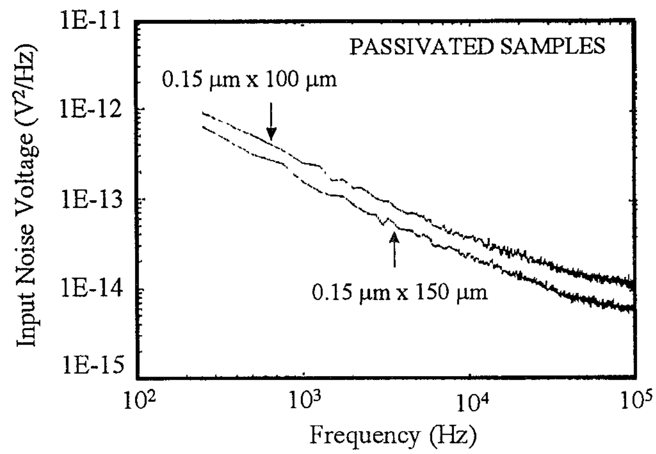

Fig.2 : Input noise voltage versus frequency for various gate widths

In order to get a better understanding of the L.F noise mechanisms, we have performed L.F noise measurements versus gate bias voltage ranging from -0.4 to 0.4 volt at 1.4 volts drain source voltage. All these spectra were analyzed assuming the superimposition of 1/f noise source and two Lorentzian noise sources (g-r) (related to trapping-detrapping effects on discrete traps in the bandgap of the sample). We have plotted on fig 3. the magnitude of these three elementary excess noise sources versus the gate-source voltage.

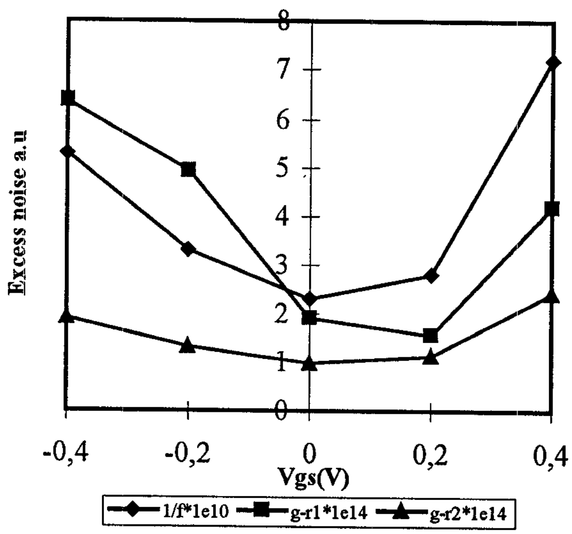

Fig.3 : Evolution of excess noise sources versus gate bias at Vds=1.4 V for a passivated device featuring 0.15x100µm² gate size

The plot indicates that there is an optimum bias condition with respect to excess noise around Vgs=0 V. This behavior indicates that the different noise sources are probably located in the δ doped AlInAs donor layer and at the interface between the AlInAs layer and GaInAs channel. The increase of noise near pinch-off voltage suggest InAlAs buffer influence or real space transfert of carriers in AlInAs layer as possible origin of noise. In order to confirm these results, we have performed noise measurements versus drain-source voltage ranging from 1 to 1.4 volts (at constant Vgs=0 V). The results indicate that the excess noise is decreasing with the carrier confinement which is consistent with traps in the δ doped AlInAs layer. We have conducted the same work for unpassivated devices and we note higher noise variations versus bias conditions.

Finally according to some published data, we present the state of the art of the L.F noise performance of microwave HEMTs devices (see Table 1).

Device	Gate size (µm²)	Substrate.	Channel	Donor layer	Doping Type	Ref
H1	1x200	GaAs	GaAs	GaInP	UD	[6]
H2	1x290	GaAs	GaAs	AlGaAs	UD	[7]
PH1	1x290	GaAs	GaInAs	AlGaAs	UD	[7]
LM1	0.15x50	InP	GaInAs	InAlAs	δD(SLG)	[5]
LM2	0.7x150	InP	GaInAs	InAlAs	UD	[4]
LM3	0.15x100	InP	GaInAs	InAlAs	δDP	our work

Table 1 :δD: planar doping, UD: uniform doping, δD(SLG) planar doping and superlattice under gate, δDP: planar doping and passivation layer.

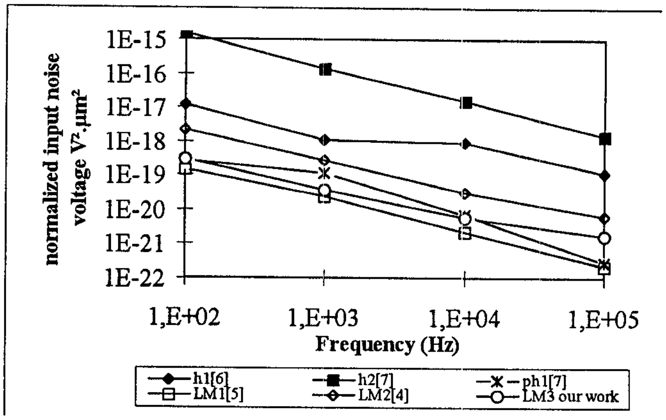

Fig.4: comparative study of LF noise for devices listed in table 1

We have plotted on Fig.4 the input referred noise voltage generator normalized with respect to the gate area for the devices listed in Table 1. The results indicate InP based HEMTs are promising candidates for low phase noise millimeter-wave applications since they exhibit the lowest normalized excess noise level. In order to conclude this work, we analyze in the next section the impact of the InP HEMTs L.F noise properties on the phase noise of a microwave oscillator.

V Residual and oscillator phase noise measurements

Residual phase noise measurements were carried out on InP devices. We have plotted on fig.5 the frequency evolution (100 Hz - 100 kHz) of the residual noise at 10 GHz phase for A and B samples and the results indicate firstly that the spectra shape are approximately the same with 1/f and two g-r noise components and secondly that passivated devices (#A) are noiseless than unpassivated ones (#B) which compares well with the results presented in section III.

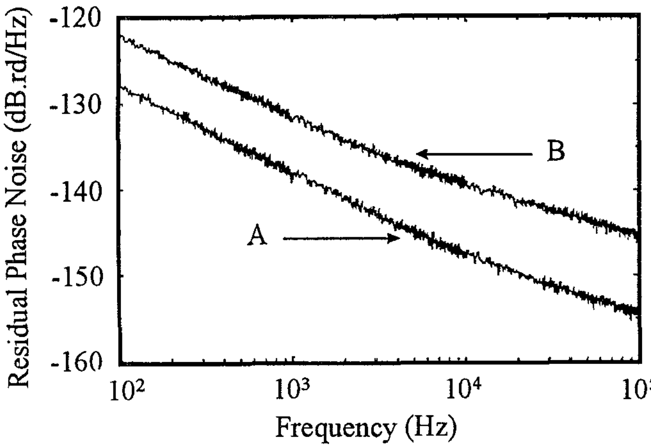

Fig 5: Residual phase noise level at 10 GHz of devices #A and #B

An oscillator has then been realized using a 3.5 GHz TM mode cavity and several devices have been tested. We have reported on Fig.6 the phase noise of this oscillator with 0.15 x 100 μm^2 passivated InP HEMT as the active element.

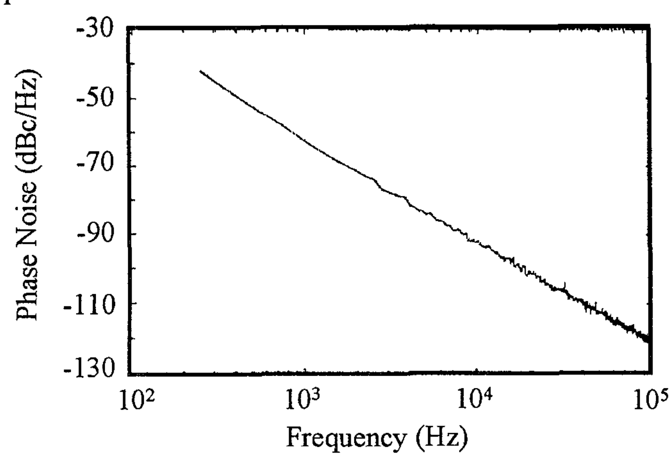

Fig.6 : Phase noise of an 3.5 GHz oscillator based on 0.15x100µm2 passivated device.

The results indicate that the shape spectra are slightly different (only 1/f noise) from those obtained on L.F noise measurements which indicate that the L.F noise components are probably modified by oscillating conditions [8]. The phase noise level of -92 dBc/Hz at 10 kHz carrier offset compare well with usual FET DRO phase noise

IV Summary

The low-frequency noise properties of 0.15 µm gate length InP based millimeter-wave HEMTs have been investigated. We have found that a significant amount of L.F noise (50%) is generated at the sample surface and can be suppressed by an appropriate silicon nitride based passivation. Nevertheless providing this noise is normalized with respect to the gate area, we have found that its level compares very well with other published data. Residual noise measurements reveal a correlation with L.F noise level and we can state that passivation process leads to an improvement of the noise performance of the device. Phase noise measurements reveal that L.F noise is probably modified by oscillating conditions. This behavior will be detailed at the conference.

References :

[1] M.Wojtowicz et al " 0.1 µm graded InGaAs channel InP HEMT with 305 GHz f_T and 340 GHz f_{max}" IEEE ED, Vol 15,N°11, Nov 1994, pp 477-479.

[2] K.H.G Duh "A super low-noise 0.1 µm T-gate InAlAs/InGaAs/InP HEMT" IEEE Microwave and Guided Wave Letters, vol 1, n°5, pp 114-116, 1991.

[3] M.Y Kao et al "An extremely Low-noise InP-based HEMT with silicon nitride passivation" IEDM94 digest, pp 907-910.

[4] G.I.Ng et al " Low-frequency noise characteristics of lattice matched (x=0.53) and strained (x>0.53) $In_{0.52}Al_{0.48}As/In_xGa_{1-x}As$ HEMTs" IEEE Trans on ED 39, n°3, 1992, pp 523-528.

[5] M.S.Thurairaj et al " Low-frequency noise Behavior of 0.15 µm Gate length lattice-matched and lattice mismatched modfet's on InP Substrates" IEEE EDL 12, n°8, 1991, pp 410-412.

[6] Y.J Chan and D.Pavlidis "Trap studies in GaInP/GaAs and AlGaAs/GaAs HEMT's by Means of low-frequency noise and transconductance dispersion characterizations" IEEE Trans on ED 41, n°5, 1994, 637-642.

[7] S.M.J LIU et al "low-noise behavior of InGaAs Quantum-Well Structure Modulation Doped FET's from 10^{-2} to 10^8 Hz" IEEE Trans on ED 33, n°5, 1986, pp 576-581.

[8] O.Llopis et al "Low-frequency noise in FETs Devices operated in Nonlinear Conditions Consequences on Oscillators Phase Noise" EMC 95 Bologna, pp285-289.