INVESTIGATION OF LOW-FREQUENCY NOISE IN ALGAN/GAN HEMT STRUCTURES UNDER ILLUMINATION

K. Rendek, A. Šatka, J. Kováč, D. Donoval

Slovak University of Technology, Faculty of Electrical Engineering and Information Technology, Institute of electronics and photonics, Ilkovičova 3, Bratislava, Slovakia
karol.rendek@stuba.sk

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1. Introduction

It is generally accepted that high electron mobility transistors (HEMTs) based on GaN will stand for the next generation of wireless and high power electronic thanks to their competitive properties. The level and spectrum of low-frequency noise is one of the important parameters determining their applications [1]. The low-frequency (LF) noise analysis is well accepted for estimation of HEMT structure quality, it is also early indicator of device failure [2]. In this paper, we report on investigation of the gate and drain low frequency noise spectral density in AlGaN/GaN HEMT transistors grown on sapphire substrates. The effects of HEMT transistors operation point and UV LED illumination with photon energy E_{ph} = 3.22eV < E_g (E_g is the band gap) on frequency noise were studied. We have found that the noise level and spectra are affected by illumination which could be related to deep levels in forbidden band.

2. Experimental

HEMT transistor structures were grown on sapphire substrate by MOCVD. The epitaxial structure consists of 3μm GaN:Fe buffer layer followed by 8nm AlGaN, 6nm GaN and 8nm undoped AlGaN layers. The device processing of HEMT transistors started with Ar reactive ion etching for mesa insulation. Optical lithography was used to define Ti/Al/Ni/Au ohmic contacts and 2μm long and 50μm wide Schottky barrier Ni/Au gates. The distance between drain and source is 6μm.

The drain and gate LF noise measurements at room temperature were accomplished in common source configuration with 470Ω resistor in series with drain and V_{DD} voltage source [3]. For the drain LF noise measurements, a linear region of the output characteristics has been chosen to suppress the effects of a long-term instability caused e.g. by local overheating. The spectrum of the drain voltage noise from the drain, amplified by 80dB low-noise voltage preamplifier was measured by signal spectrum analyser SR770 in the 4Hz-100kHz range. The gate current noise i_{nGS} from the reverse biased gate Schottky contact was converted to voltage by low-noise current pre-amplifier SR570. For precise spectrum measurements in the 0.6Hz-120kHz range, signal spectrum analyzer based on acquisition board EVAL-CED1Z and evaluation board EVAL-AD7760/AD7762EDZ has been adopted. Measurement software has been developed in LabView.

3. Results and discussion

To deeply investigate the nature of LF noise in HEMT structures, the LF noise spectra were taken from the investigated devices at given operation point under the conventional dark conditions and then under the illumination by LED. The UV LED with photon energy E_{ph} = 3.22eV and 2mW luminescence power was used for illumination. We have found that the operation point, mainly drain-source voltage V_{DS} and slightly the gate-source voltage V_{GS} of investigated transistors has changed during the illumination as a result of carrier generation. Therefore, two procedures were used for the drain voltage noise measurements under the illumination. In the first case the V_{GS} and V_{DS} were left changed according to illumination level (Figure 1a), whereas in the second case the V_{GS} and V_{DS} of illuminated transistors were set to the value before the illumination (Figure 1b). In case of the gate current noise measurements, V_{DD} voltage was set to 1V and V_{GS} was kept constant during both dark and UV LED illumination conditions. To keep stationary measurement conditions, the noise measurements were realized with approx. 3 min delay after the LED turning on or off.

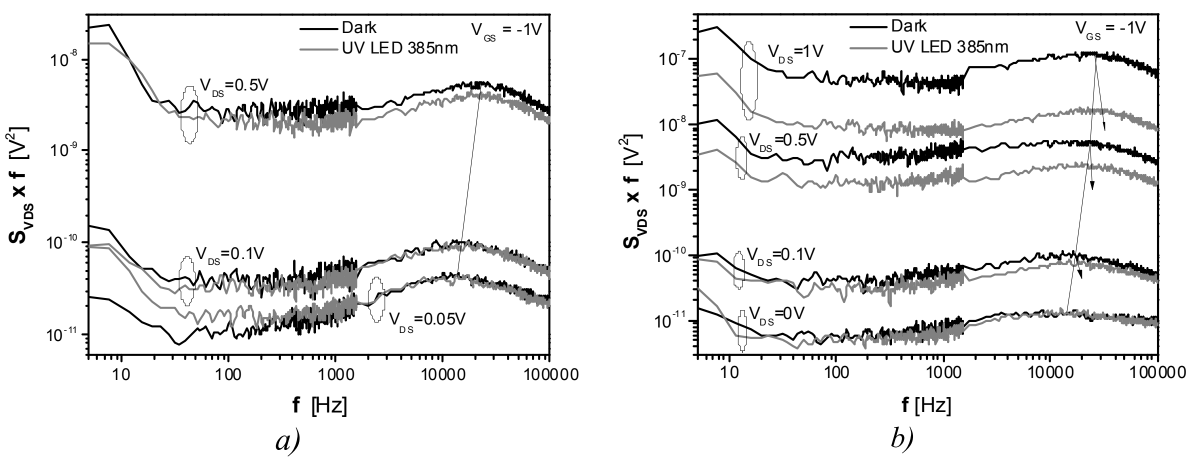

Fig. 1: *The drain voltage noise spectral density of AlGaN/GaN HEMT before (black) and after (grey) UV illumination at various drain voltages V_{DS} and V_{GS} = -1V, with (a) and without (b) tuning of the DC operation point.*

The drain voltage noise spectra measured in linear regime of AlGaN/GaN HEMT transistor at V_{GS} = -1V for drain voltages V_{DS} from 0 to 1V are shown in Figure 1. To separate the G-R noise sources from pure 1/f noise, the measured spectral densities were multiplied by frequency, so that every bulge on the curve represents the G-R noise source. Using this simple technique the uncorrelated G-R noise sources exceeding the 1/f noise at frequencies below 30Hz and at above 10kHz were found from the measurements in Figure 1. It has been found that the increase in V_{DS} under the dark conditions results in a slight increase of characteristic frequency f_c of G-R noise at 10kHz, whereas spectra in low frequency region are not changed significantly. We have found that the illumination of the HEMT with tuning of the DC operational point has only a little effect to the drain voltage noise spectra as can be seen in Figure 1a). On the other hand, the UV illumination resulted in significant decrease of spectral noise density (nearly one order at a given experimental conditions) and shift of G-R noise characteristic frequency f_c at 10kHz to higher frequencies for all DC operation points.

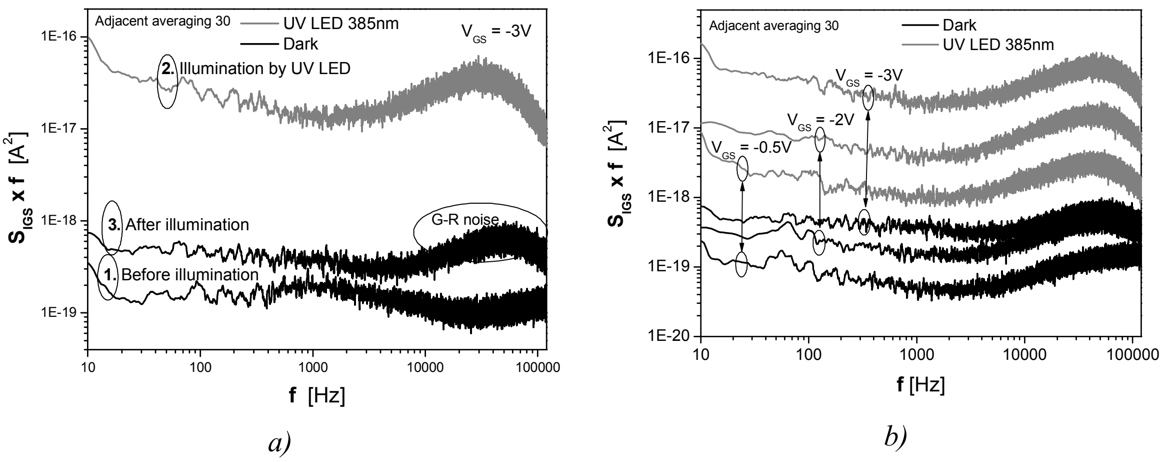

Fig. 2: *a) Long-term influence of the UV illumination to the gate current noise of AlGaN/GaN HEMT, b) The evolution of the gate current noise spectra of AlGaN/GaN HEMT with the gate voltage* V_{GS} *and illumination.*

The drain noise consists of fluctuations from the gate and the channel. The value of 1/f voltage noise, originated from the conductivity fluctuations in the channel has substantial contribution to the whole drain voltage noise spectra [4], but there is no straightforward method to distinguish between these two sources. The gate current noise spectra measured for V_{GS} from 0 to -4V are shown in Figure 2. In Figure 2a, the numbers 1 to 3 represents chronological process of noise measurements at the same operation point. Initially, there was only a low G-R noise in the spectrum, but after the illumination the overall 1/f noise increased more than two decades and G-R noise source at 40kHz becomes evident.

Interestingly, after the illumination turning off this G-R noise component became evident for more than 24 hours (curve 3. in Figure 2b). From this follows that deep levels in forbidden band stayed activated which in turn influences the G-R noise located in higher frequencies. The same features were observed at various DC operation points (Figure 2b), where G-R noise became dominant over 1/f noise and characteristic frequency f_c has slightly changed to higher frequencies with V_{DS}.

The observed changes of DC operation point, gate and drain noise spectra at the illumination of undoped InAlN/GaN structure by photon energy $E_{ph} = 3.22$eV may not be explained by a simple near-band generation of carriers in the vicinity of 2DEG in GaN or InAlN because of the low energy of illuminating photons. The most probably, there is a change in the occupation statistics of the trapping centres, which leads to the change in emission/trapping rates responsible for G-R noise and increased conductivity of the channel as well as strong carrier capture in the InAlN barrier.

4. Conclusion

The study of low-frequency noise in AlGaN/GaN HEMTs illuminated with photon energy E_{ph} bellow E_g indicates important contribution of the traps to both the gate and the drain noise of the structures, which influence both 1/f and generation-recombination noise components.

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