Generation-Recombination noise analysis in ungated HEMT structure to determinate the activation energy and capture cross-section of traps

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Low frequency noise of ungated GaAs/AlGaAs two-dimensional electron gas (2 DEG) heterostructure grown by molecular beam epitaxy (MBE) was investigated over a wide range of temperatures from 4 K to 300 K. In the frequency range from 1 Hz to 100 KHz, noise power spectral densities (PSD) can be described as superposition of flicker noise, thermal noise and several generation-recombination (G-R) noise components. The temperature dependence of the (G-R) noise arising from the traps was used to deduce the thermal activation energies and cross sections. The present results are compared to those of the literature to identify the physico-chemical nature of traps responsible of the G-R noise.

Keywords: GaAs/AlGaAs, 2DEG, low frequency noise, G-R noise, activation energy, cross section, traps.

I. Introduction

The low frequency noise in a device is sensitive to the device technology, especially the presence of traps and defects. Hence, important information on the reliability and sensitive parameters for the current transport can be reached from the study of low frequency noise [1,2].

The study of low frequency noise (LFN) technique in a AlGaAs/GaAs/AlGaAs heterostructure allows us to determine the nature of the traps from which originates the G-R noise. Activation energies and trap cross-sections are extracted from noise spectra taken at different temperatures. Since, discrete energy levels in the forbidden gap are able to trap electrons or operate as recombination centers. Theory explains that these traps cause G-R noise contributions in the total noise spectra. The results of this experimental method explain the degradation of the noise performances when a device is biased and used in cryogenic applications as preamplifiers for infrared or visible sensors.

II. Experimental details

II-1. Sample description

The AlGaAs/GaAs heterostructure was grown on a semi-insulating <100> GaAs substrate by molecular-beam epitaxy (MBE). Table 1 summarizes technical description of the sample [3].
The samples are similar a HEMTs but without control gate or as a sheet resistance represented by a GaAs channel with a two-dimensional electron gas (2DEG).
The dimensions of the samples are: length L = 16, 11, 8 and 7 µm, and the width W = 500 µm.

Layer	Material	Thickness
Cap layer	n+ GaAs	10 nm
Barrier	n $Al_xGa_{1-x}As$ (x = 19.6%)	
Donor	n+ AlGaAs	15 nm, SiAs: 8×10^{12} cm^{-2}
		35 nm, Si: 10^{12} cm^{-2}
Spacer	AlGaAs	40 nm
Channel	GaAs	20 nm
	$Al_xGa_{1-x}As$	10 nm
Substrate	GaAs	45 nm

Table 1: Technical description of the sample used in the study.

II-2. Electrical measurements:

The measurements of spectral noise were performed at various temperatures from 300 K down to 4 K, and for different applied voltages. The voltage noise was amplified by an EG&G 5004 low-frequency noise voltage amplifier, of which amplification was fixed to G = 10^3, equivalent noise voltage of the order of 0.8 nV/√Hz, and equivalent noise current of 92 fA/√Hz at 1 kHz.
Noise measurements were performed using a HP 35665A spectrum analyzer in the frequency range of 1 Hz - 100 kHz [3].

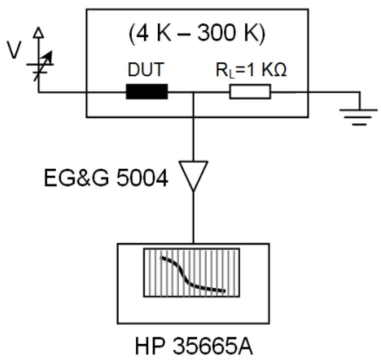
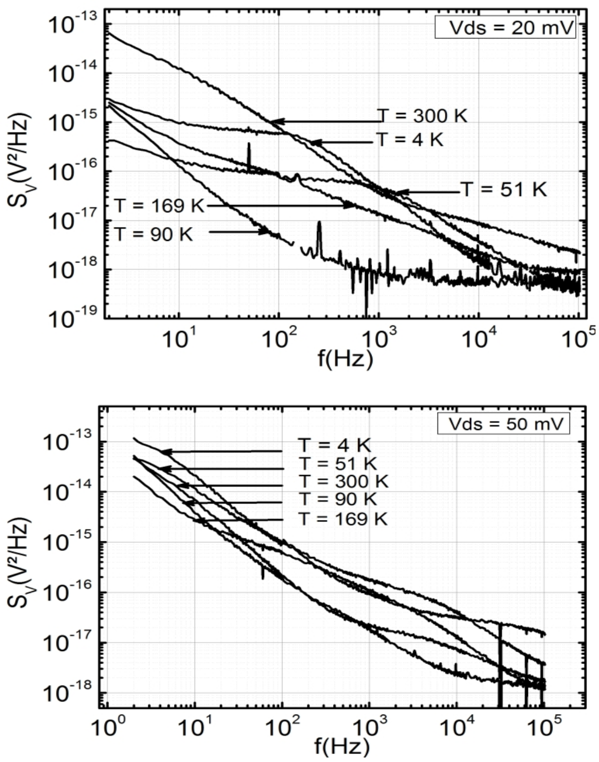


Figure 1 : A Simplified experimental setup for the low frequency noise measurements.

The sample was mounted on a sample holder located at the end of a cryogenic cane that can be directly put in a helium reservoir. The temperature was measured by a 330 lake shore controller. The sample was maintained at a long enough time (~10 min) at a given temperature before making each measurement in order to be sure that the thermodynamic equilibrium was reached. All measurements are made in the dark condition.

III. Experimental results

Figure 3 gives typical total spectra of the noise in the low frequency range for different applied voltages taken at various temperatures.



Figures 2: Total noise spectra at 20 mV and 50 mV at various temperatures.

Noise in semiconductor is affected by various parameters such as conductivity, defect density, temperature, doping concentration, and bias voltage. However, when bias or temperature are varied, the semiconductor properties are no longer constant. The value of the total noise increases with the applied voltage related through ohm's law [4]. When the temperature is lowered, the situation is not clearer [5, 6]. This is due either to saturation of the current resulting from the high increase of the 2DEG mobility, or the presence of Lorentzian noise at very low frequency which could be due to the shift of some cutoff frequencies [7, 8].

In order to describe temperature and applied voltage effects on each noise contribution, we will proceed to separate between all the low frequency noise components [9, 10]:

$$S_v = \frac{\alpha_H \times V_{ds}^2}{N \times f^\gamma} + \sum_{j=1}^{M}\left[\frac{A_j \times \tau_j \times V_{ds}^2}{1+(2\pi \times f \times \tau_j)^2}\right] + S_{Th} \qquad (1)$$

S_v is the voltage noise power spectral density,
A_j is proportional to the variance of the fluctuating number of charge carriers,
α_H is an empirical constant, and γ is the frequency exponent (Hooge's parameters),
V_{ds} is the applied voltage (drain - source),
N (= $n_s \times L \times W$, where n_s is the 2DEG density) is the number of carriers in the sample,
τ_i ($=1/2\pi \times f_i$) is the trapping time constant.

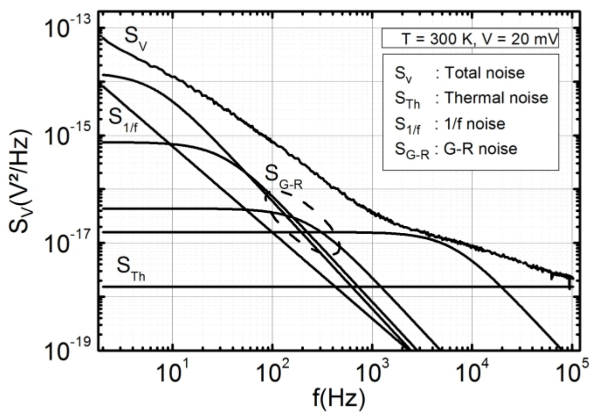


Figure 3: Decomposition of the Total noise spectra at 300 K and V = 20mV.

All obtained spectra were fitted to separate between the *1/f* noise and the others G-R noises and thermal noise (S_{Th}).

We can extract the corner frequency f_i or the trapping time constant τ_i by multiplying the total noise by frequency ($f \times S_v$) and plot it against frequency but this

method doesn't give precise values because of the flatness of the peak [11].

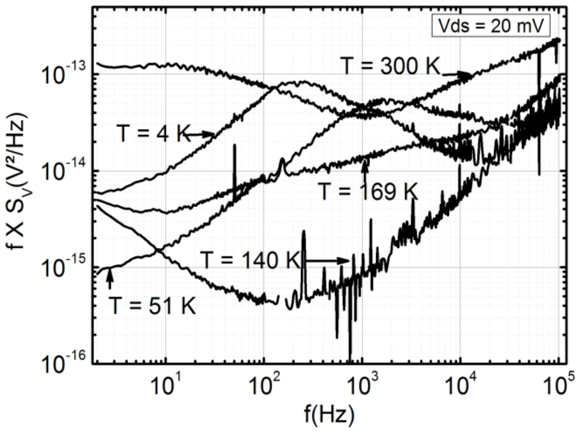


Figure 4 : The $f \times S_V(f)$ noise spectrum for different temperatures at V = 20 mV

The curve fitting method is used to extract more precisely f_i, thermal activation energy (E_a) and capture cross-section (σ) of traps.

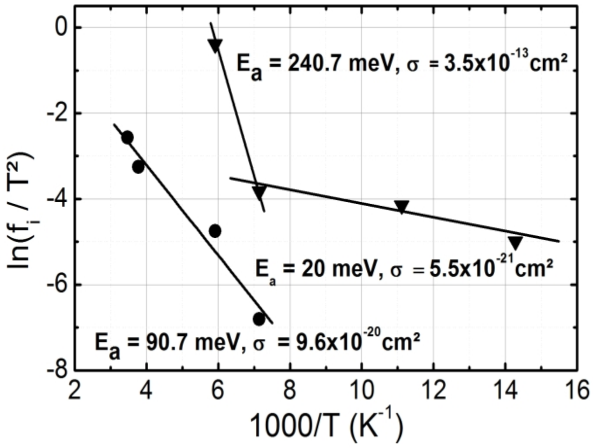


Figure 5: Arrhenius diagram of fi versus 1000/T.

E_a is extracted from the slope of the Arrhenius plot and the trap capture cross section can be calculated from the intercept with the vertical axis [7].

The trap represented by E_a = 90.7meV and σ=9.6×10^{-20} cm^2, is similar to the trap P1 characterized by 91 meV and 1.7×10^{-18} cm^2 [12]. If this was the case, it would be situated at the 2DEG/electrode interfaces. This trap and the second presented by 20 meV are similar to those found by Li et al. [13] in submicron GaAs/AlGaAs Hall devices. The trap characterized by the activation energy of E_a = 240.7 meV and by σ = 3.5×10^{-13} cm^2 could be similar to trap EL2 which was related to AsGa antisite defects [14].

IV. Conclusion

A two-dimensional electron gas has been characterized by the low frequency noise (LFN) method. The study was made at different applied electric fields, and for various temperatures, ranging from 300 K down to 4 K. Different contributions (thermal noise, G-R noise and 1/f noise) have been identified. Analysis of the G-R noise in temperature was used to calculate the activation energy of traps responsible for capture/emission of carriers in a device and thus contributing to the device noise. LFN method appears to be the simplest technique to measure such defects in semiconductors and gives valuable information to assess the quality of the fabrication process.

V. References

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