ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2009. No. 4(92)
ELEKTRONIKA IR ELEKTROTECHNIKA

T170 ELECTRONICS
ELEKTRONIKA

The *1/f* Noise in a Two-Dimensional Electron Gas: Temperature and Electric Field Considerations

S. Mouetsi, A. El Hdiy
Université de Reims, Champagne–Ardenne,
Laboratoire de Microscopies et d'Etude de Nanostructures (EA 3799), Bât. 6, case n°15, UFR Sciences, 51687 Reims Cedex 2, France, phone: +33 326913223, e–mail: souheil.mouetsi@univ–reims.fr
M. Bouchemat
LMI, Département d'Electronique, Faculté des Sciences de l'Ingénieur, Université Mentouri, Constantine, Algérie

Introduction

The principal operation of semiconductor devices is based on the motion of carriers in the conduction and valence bands. The presence of defects and impurities causes damages and large fluctuations in the electric conductivity via fluctuations in the carrier density [1] or in their mobility [3], or in the both [3–5]. For this reason, the control and the evaluation of the reliability of materials and devices are necessary in microelectronic and optoelectronic fields. Better knowledge of the most important failure mechanisms affecting electron devices and systems was required in order to improve their reliability. Experiments on many systems have shown that the noise level rises as a device degrades during its life, and also that a device which, immediately after manufacture, shows high levels of noise has a short life. Among device characterization methods, the low frequency noise is usually used because it is a sensitive and non destructive reliability indicator [6].

This paper is concerned with low frequency measurement of *1/f* noise (i. e. with a frequency spectrum proportional to $1/f^{\gamma}$ with $0.8 < \gamma < 1.8$) made on an AlGaAs/GaAs structure which is similar to a HEMT (high electron mobility transistor) but without a control gate.

We report on the measurements of noise power spectral density (PSD) of the studied sample. Fitting curve decomposition of the total PSD gives different noise contributions: *1/f* noise ($S_{1/f}$), generation - recombination noise ($S_{G\text{-}R}$) and thermal noise (S_{Th}).

We are essentially interested in the study of *1/f* noise at various temperatures and for different applied voltages. That is why; we only study the variation of Hooge's parameters (α_H, γ) with temperature. Furthermore, we calculate the contact resistances from the thermal noise wherein allows us to get the values of the channel resistance and its variation with temperature.

Experiment Details

The sample used in this study was grown on a semi-insulating <100> GaAs substrate by molecular-beam epitaxy (MBE). The AlGaAs/GaAs heterostructure consists of a 10 nm GaAs cap layer, a 15 nm $Al_xGa_{1-x}As$ layer (x = 19.6%) followed by a delta doping layer Si δ-doping with a density of 8×10^{12} cm^{-2}. An $Al_xGa_{1-x}As$ layer of 35 nm thick (x=19.6%) with a Si δ-doping density of 10^{12} cm^{-2}, an $Al_xGa_{1-x}As$ spacer layer of 40 nm, followed by a GaAs well of 20 nm, and an $Al_xGa_{1-x}As$ (x = 19.6 %) layer. A detailed description of the sample elaboration can be found elsewhere [7] and are presented in the table 1.

Table 1. Structure layer of low density heterojunction

Cap layer	GaAs	10 nm
Barrier	$Al_xGa_{1-x}As$ (x = 19.6%)	15 nm
δ-doping	SiAs	8×10^{12} cm^{-2}
Barrier	$Al_xGa_{1-x}As$ (x = 19.6%)	35 nm
δ-doping	Si	10^{12} cm^{-2}
Spacer layer	$Al_xGa_{1-x}As$ (x = 19.6%)	40 nm
channel	GaAs	20 nm
	$Al_xGa_{1-x}As$ (x = 19.6%)	10 nm
Superlattice		250 nm
	GaAs	500 nm
	$Ga_{1-y}In_yAs$ (y~10%)	12 nm
	AlAs	10 nm
	GaAs	60 nm
Substrate	GaAs	45 nm

The plot electrodes were made by evaporation of Ni on the GaAs layer followed by evaporation of Au/Ge eutectic. Two metallic layers made of Ni and Al were then successively deposited. Lastly, the sample was warmed at about 400 °C to allow Ge to diffuse through GaAs.

This diffusion reduces the created depletion layer under metallic contacts. The studied sample is similar to a sheet resistance represented by a GaAs channel with a two-dimensional electron gas (2DEG). In other word, the sample is similar to a HEMT without a control gate. The sample dimensions are: $L = 16$ μm, and the width $W = 500$ μm.

The low frequency noise of device under test (DUT) is measured with the simplified experimental setup shown in Fig. 1.

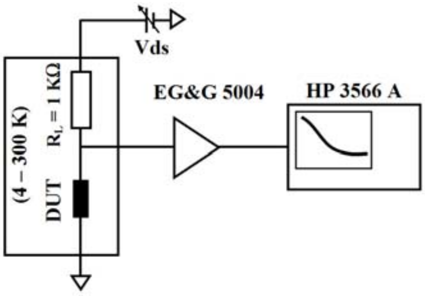

Fig. 1. A Simplified experimental setup for the low frequency noise measurements

This system is polarized by a dc bias fixed at a given value: 0 and 100 mV. The voltage noise is amplified by an EG&G 5004 low-frequency noise voltage amplifier, of which amplification is 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 are performed using a HP 35665A spectrum analyzer in the frequency range of 1 Hz–100 kHz. The sample is mounted on a sample holder located at the end of a cryogenic cane that can be directly put in a helium reservoir. The temperature is measured by a 330 lake shore controller. The sample is 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 is reached. All measurements are made in the dark condition.

Experimental Results

The noise spectral density was measured at 51 and 264 K for 0 and 100 mV as shown in Fig. 2.

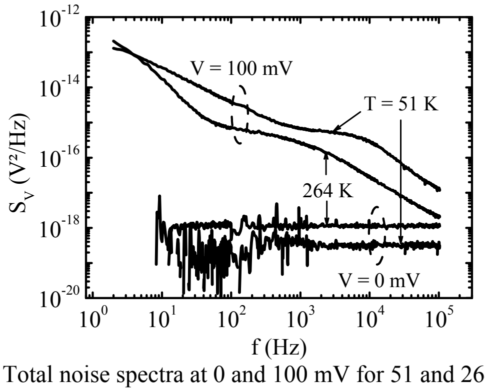

Fig. 2. Total noise spectra at 0 and 100 mV for 51 and 264 K

A sample spectrum, showing *1/f* noise and other contributions, 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, why the value of the total noise increases with the applied voltage related through ohm's law as well known and as reported in the literature [8], but when the temperature is lowered, a shift of the cutoff frequencies towards lower values occurs, new levels appear [9]. However the sample spectrum according to variations of temperature was unexplained [10].

A typical decomposition of the power noise spectral density to different components is shown in Fig. 3 wherein we can observed: Thermal noise (S_{Th}), *1/f* noise ($S_{1/f}$) and one or several G-R noise components ($S_{G\text{-}R}$).

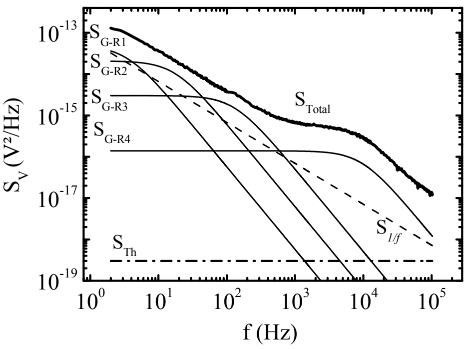

Fig. 3. Decomposition of the PSD into $S_{1/f}$, S_{Th} and $S_{G\text{-}R}$ noise's at V = 100 mV for T = 51 K

The results of Fig. 3 are obtained by fitting the experimental noise PSD data using the following equation:

$$S_V(f) = \frac{\alpha_H V^2}{N f^{\gamma}} + \sum_{j=1}^{n} \frac{A_j \tau_j V^2}{1 + (2\pi\tau_j f)^2} + S_{th}\,, \qquad (1)$$

where S_v – the voltage noise power spectral density; A_j – proportional to the variance of the fluctuating number of charge carriers; α_H – an empirical constant (Hooge parameter); V – the applied voltage; N – the number of carriers in the sample; γ – the frequency exponent. The second term in the right of equation (1) represents $S_{G\text{-}R}$ resulting from a sum of n distinct trap levels. At a given temperature, each trap level is characterized by a specific time constant (τ_j) [11].

As we mentioned above, we are interested essentially on the *1/f* noise. And because the resistance varies with the inverse of mobility and charge, fluctuations in one of these two quantities generates *1/f* noise. This has lead to the two major principles on which most *1/f* theories are based: carrier density fluctuation and mobility fluctuation modeling [1–5]. In that case the noise fluctuations in a given resistance are given by the Hooge empirical expression [1, 9–11]:

$$S_{1/f}(f) = \frac{\alpha_H V^2}{N f^{\gamma}}\,. \qquad (2)$$

The Hooge parameter has been investigated as a measure of the *1/f* noise amplitude, because it is possible to use it as a reliability characterization of a device.

Fig. 4. gives the variation of α_H and of γ as a function of the temperature at $V = 100$ mV.

Evolution of the both Hooge's parameters is fluctuating as a function of temperature which they show a relative decrease with temperature as shown in Fig. 4. Our results are consistent with those of [8, 12] for α_H and for γ where it was shown that despite fluctuations, α_H and γ varies with temperature.

As we noted in the introduction that the low frequency electrical noise is well accepted as a very sensitive measure of the quality and reliability of electronic devices [8]. Thus the thermal noise could be used to characterize the electric contacts, by extracting contact resistance values.

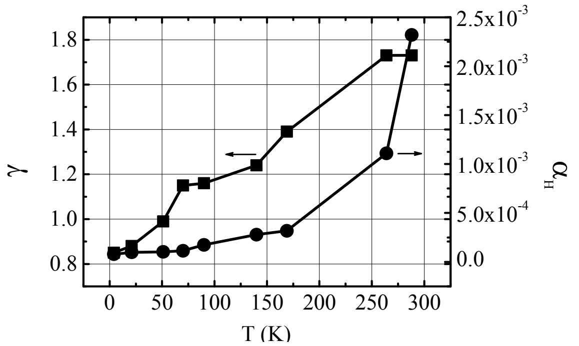

Fig. 4. Variation of αH and of γ as a function of the temperature

The thermal noise is caused by random of current carriers. The spontaneous fluctuations in voltage across a resistor due to the Brownian motion of carriers have a white spectrum given by [13]:

$$S_{Th} = 4kTR_T \, , \tag{3}$$

where k_B – the Boltzmann constant; T – the temperature; R – the total resistance of the ohmic sample. Which the resistance R_T consists of two parts: contacts resistances (R_a) independent of sample length (L), and a channel resistance (R_c) related to the material and having an L dependency

$$R_T = 2\times R_a + R_c \, . \tag{4}$$

In equation (1), the thermal noise is negligible in the experimental spectra as previously quoted in [7] (~ 1.3×10^{-18} V^2/Hz at ~300 K and ~ 4.17×10^{-20} V^2/Hz at 4 K) and showen in Fig. 3. This noise is usually dominated by the *1/f* and G-R noises [9] and it includes the contribution of the contacts resistance and the channel resistance (whose noise can be calculated from the channel conductivity; $R_C \propto \sigma^{-1} = (qn_s\mu)^{-1}$; where q is the electronic charge, n_s the surface density of the 2DEG in the channel and μ is its mobility).

The deduced total resistance at 300 K is ~ 97 Ω and at 4 K is ~ 330 Ω. The variation of S_{Th} in equation (3) is approximately linear as a function of R_T measured in the absence of any electric bias. In another way S_{th} varies linearly with the length of the channel ($R=\rho L/W$, ρ is the resistivity), and this allows us to access to the thermal noise resulting from the contacts. The thermal noise due to the contacts is ~10^{-20} V^2/Hz and if there is no correlation, this gives $R_a \approx 0.36$ Ω, where R_a is the contact resistance at the source or the drain (we assume that the both contacts are similar), which allows us to neglect the effect of the contacts on the noise. In addition, this proves that the electrical contacts are very good at room temperature. To verify the conduction behavior of the metallic electrodes, we present in Fig. 5 the total resistance R_T from the thermal noise S_{th} as a function of temperature and deduced the contact resistance ($2\times R_a$) by subtracting the calculated channel resistance from R_T. R_T increases while the R_c decreases when decreasing the temperature.

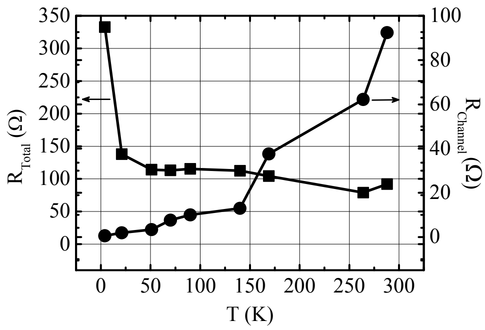

Fig. 5. The sample resistance (channel and total resistance) variation as a function of the temperature

This indicates that the contact resistance increases resulting from degradation of ohmic contacts in the Au/Ni/Ge structure constituting the electrodes.

Conclusion

In the present paper, we have studied the low frequency noise in the AlGaAs/GaAs heterostructure as a function of frequency in wide temperature range and for different applied voltages, the measured PSD shows that:

1. Different noise contributions exist in the total noise: *1/f* noise ($S_{1/f}$), generation - recombination noise (S_{G-R}) and thermal noise (S_{Th}).
2. *1/f* frequency and bias voltage dependence of PSD in the temperature range 4 – 300 K.
3. Dependence of the both Hooge's parameters (α_H,γ) on temperature.
4. Possibility to deduct the value of contacts resistances by studying the variation of thermal noise as a function of channel length.
5. A weak contribution of the contacts resistances in the total noise.

References

1. **Hooge F. N.** 1/*f* noise is no surface effect // Phys. Lett. A – 1969. – Vol. 29. – P. 139–140.
2. **Marin M., et al.** Low frequency noise characterization in 0.13 μ m p–MOSFETs. Impact of scaled–down 0.25, 0.18 and 0.13 μm technologies on *1/f* noise // Microelect. Reliab. – 2004. – Vol. 44. – P. 1077–1085.
3. **McWhorter A. L.** *1/f* noise and germanium surface properties // In Semiconductor Surface Physics, edited by R. H. Kingston, University of Pennsylvania, Philadelphia. – 1957. – P. 207–228.
4. **Mikoshiba H.** *1/f* noise in n–channel silicon–gate MOS transistors // IEEE–Trans. Electron Dev. 29, 965 (1982).
5. **Van der Ziel A., Tong H.** Low frequency noise predicts when a transistor will fail // Electronics. – 1996. – Vol. 39. No. 24. – P. 95–97.
6. **Ciofi C., Neri B.** Low–frequency noise measurements as a characterization tool for degradation phenomena in solid–state devices // J. Phys. D: Appl. Phys. – 2000. – Vol. 33. – P. R199–R216.
7. **Khlil R., El Hdiy A., Jin Y.** Deep levels and low–frequency noise in AlGaAs/GaAs heterostructures // J. Appl. Phys. – 2005. – Vol. 98. – P. 093709-1– 093709-4.
8. **Tacano M., et al.**. Dependence of Hooge parameter of InAs heterostructure on temperature // Microelec. Reliab. – 2000. – Vol. 40. – P. 1921–1924.

9. **Delseny C., et al.** Excess Noise in AlGaAs/GaAs Heterojunction Bipolar Transistors and Associated TLM Test Structures // IEEE Trans. Elect. Dev. – 1994. – Vol. 41. No. 11. – P. 2000–2005.
10. **Voss R. F., Clarke J.** Flicker (*1/f*) noise: Equilibrium temperature and resistance fluctuations // Phys. Rev. B. – 1976. – Vol. 13. – P. 556–573.
11. **Kar S., Raychaudhuri A. K.** Temperature and frequency dependence of flicker noise in degenerately doped *Si* single crystals // J. Phys. D: Appl. Phys. – 2001. – Vol. 34. – P. 3197–3202.
12. **Berntgen J., et al.** Hooge parameter of InGaAs bulk material and InGaAs 2DEG quantum well structures based on InP substrates // Microelectronics Reliability. – 2000. – Vol. 40. – P. 1911–1914.
13. **Johnson J. B.** Thermal Agitation of Electricity in Conductors // Nature. –1927. – Vol. 119. – P. 50–51.

Received 2009 02 15

S. Mouetsi, A. El Hdiy, M. Bouchemat. The *1/f* Noise in a Two-Dimensional Electron Gas: Temperature and Electric Field Considerations // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 4(92). – P. 3–6.

A two-dimensional electron gas in an AlGaAs/GaAs heterostructure has been characterized by the low frequency noise method for various temperatures. Different contributions (thermal noise, generation – recombination noise and *1/f* noise) have been identified. The *1/f* noise has been extracted from the total noise and Hooge's parameters have been determined and analyzed on a function of temperature. The parameters showed a decrease with the temperature. Measurements of the thermal noise versus device length of the sample permitted us to estimate the contribution of the contact noise and the results showed the good quality of contacts. Ill. 5, bibl. 13 (in English; summaries in English, Russian and Lithuanian).

С. Моуетси, А. Ел Гди, М. Боихемат. *1/f* шум в двумерном электронном газе: влияние температуры и электрического поля // Электроника и электротехника. – Каунас: Технология, 2009. – № 4(92). – С. 3–6.

Были исследованы характеристики низкочастотного шума двумерного электронного газа в AlGaAs/GaAs гетероструктурах при различных температурах. Установлены различные воздействия тепловых, рекомбинационных и *1/f* шумов. Из общего шума выделены *1/f* шумы и определены Hooge параметры, которые проанализированы при различных температурах. Установлено, что при уменьшении температуры шумы уменьшаются. Измерение теплового шума позволило отделить шумы контактов и подтвердить хорошее качество указанных контактов. Ил. 5, библ. 13 (на английском языке; рефераты на английском, русском и литовском яз.).

S. Mouetsi, A. El Hdiy, M. Bouchemat. Temperatūros ir elektrinio lauko įtaka *1/f* triukšmui dvimatėse elektroninėse dujose // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 4(92). – P. 3–6.

Žemojo dažnio triukšmo metodu apibūdintos dvimatės elektroninės dujos AlGaAs/GaAs heterostruktūrose esant įvairioms temperatūroms. Nustatyti skirtingi poveikiai (terminių triukšmų, rekombinacijos triukšmų ir *1/f* triukšmo). *1/f* triukšmas buvo išskirtas iš bendro triukšmo. Hooge parametrai, kurie buvo nustatyti ir išanalizuoti kaip temperatūros funkcija, mažėja mažėjant temperatūrai. Terminių triukšmų matavimo duomenys palyginti su pavyzdžio matavimo duomenimis. Gauti rezultatai parodė gerą kontaktų kokybę. Il. 5, bibl. 13 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).