Analysis of parameters affecting the flicker noise in a two-dimensional electron gas in an AlGaAs/GaAs heterostructure

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Abstract: We studied the effect of the most important parameters affecting noise at low frequency in a bi-dimensional electron gas at different temperatures from 300 K down to 4 K, and at two bias voltages (20 and 50 mV). The flicker noise (or *1/f* noise) is characterized by the well known Hooge's expression, and parameters are analyzed; γ increases with the sample length to reach saturation, while α_H presents a linear increase. They also increase with temperature; γ varies linearly independently of the bias, and α_H varies as ~exp(T/T_0) depending on the applied bias. The flicker noise origin is identified as being the carrier mobility fluctuation which is likely dominated by the lattice phonons.

Keywords: AlGaAs/GaAs, two-dimensional electron gaz (2DEG), low frequency noise, flicker noise.

I. Introduction

Low-frequency electrical noise is well accepted as a very sensitive measure of the quality and reliability of electronic devices [1, 2]. Furthermore, conduction fluctuations often provide information about the scattering process. It soon became clear that a better knowledge of the most important failure mechanisms affecting electron devices and systems was required in order to improve their reliability. In many semiconductor devices, fluctuations in *1/f* or flicker noise dominate at low frequencies and it depends on the material, temperature, contact quality, surface treatment, mobility fluctuations and carrier concentration fluctuations.

The origin of low frequency noise was attributed to different parameters depending on the kind of the studied devices, and was used to identify some physical parameters. For example, several studies on the electrical noise in semiconductor components have highlighted correlation between some extrinsic parameters of the studied device (including electrically active defects) and the appearance of noise [3 - 6]. As a consequence, the noise measurement can be used not only to determine the minimum noise parameters of the components, but also for the identification of heterogeneity and defects induced by the growth process and manufacturing.

The aim of the present study is analyzing voltage spectral density to extract the principal parameters; namely, the Hooge parameters α_H and γ. The temperature dependence is taken into account and results are compared to those of the literature. The α_H parameter is analyzed on term of lattice and impurity scattering, and results indicate that the *1/f* noise is in the lattice mobility fluctuations.

II. Experiment

2.1. Sample preparation

The sample used in this work 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. The channel length (L) has been defined by the e-beam JBX-5DII nanolithography writer system. The general lithographic steps were: the (Al, In) GaAs/GaAs wafer was firstly spun on a PMMA resist and baked at 170 °C; then it was exposed by the e-beam with a dose of about 400 µC/cm^2 and developed in MIBK-isopropyl alcohol. The device was realized mainly as follows: first, the active 2DEG area was defined by mesa with a chemical wet etching in H_2O_2:H_3PO_4:H_2O; then, ohmic contacts for the source and the drain, were obtained by the Au/Ge eutectic alloy as following; 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. Finally the samples were warmed at about 400 °C to allow Ge to diffuse through GaAs. This diffusion reduces the created depletion layer under metallic contacts. The absence of the control gate allows us to directly study the two-dimensional electron gas (2DEG), which is similar to a sheet resistance.

2.2. Measurement procedure

The measurements of spectral noise were performed at various temperatures from 300 K down to 4 K, and for two applied voltages (20 and 50 mV). We choose not to exceed 50 mV to avoid current saturation. Indeed, at low temperature, current increases hardly to reach saturation and this may affect the *1/f* noise by appearance of an eventual generation – recombination noise. 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. 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 minutes) at a given temperature before making each measurement in order to be sure that the thermodynamic equilibrium was reached. All measurements were made in the dark condition. During measurements the sample was submitted to 20 and 50 mV at each temperature.

III. Results and discussions

To study the *1/f* noise, measurements were limited to very low frequency (<100 Hz) and all spectra were well fitted by the known Hooge's expression:

$$\frac{S_I(f)}{I^2}=\frac{S_V(f)}{V^2}=\frac{\alpha_H}{N\times f^{\gamma}} \qquad (1)$$

where α_H is the Hooge coefficient, *f* the frequency, γ a constant and *N* (=$W\times L$; *L* and *W* are the channel length and width, respectively) is the total number of carriers. *V* and *I* are the applied voltage and the measured current, respectively.

Figure 1 gives a typical result of *1/f* noise obtained in the sample as a function of the channel length. Note that sometimes at frequencies close to 100 Hz, a deformation is shown in the spectrum which is related to the appearance of the generation – recombination noise. In this case, we limit our measurement to frequency lower than 100 Hz to avoid this noise, and reduce eventual errors in determination of the Hooge's parameters.

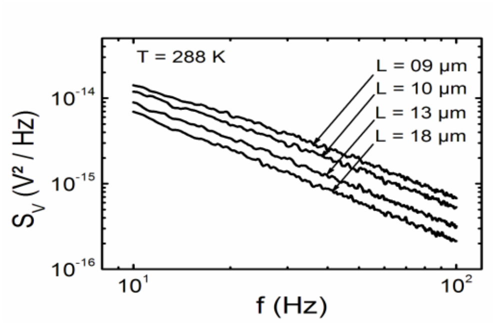

Fig.1. Typical spectra of the *1/f* noise obtained in the studied sample as a function of the channel length L at room temperature.

All spectra are fitted by the Hooge's model to extract γ and α_H. And we make sure that model coincides well with each spectrum at each temperature and for both applied biases. From spectra given in Fig. 1, we extract γ and α_H as a function of *L*. The results are given in Figs. 2 and 3.

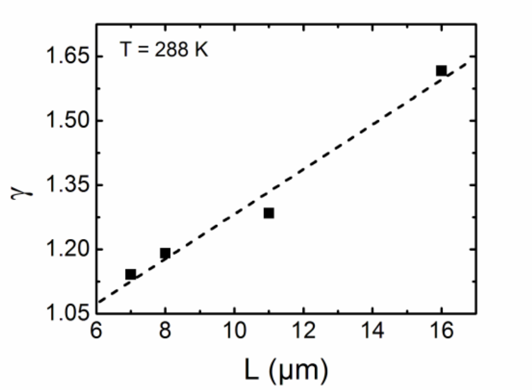

Fig.2. Variation of γ as a function of the channel length at room temperature.

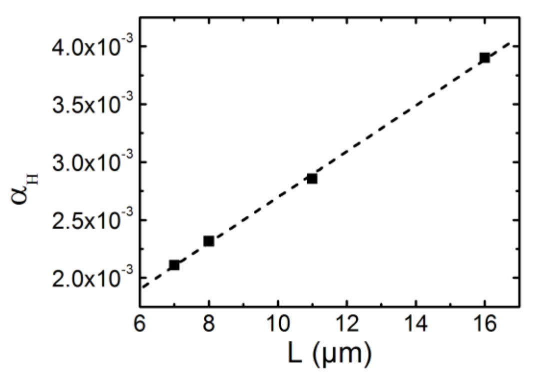

Fig.3. Variation of α_H as a function of the channel length at room temperature.

The variation of γ with *L* seems to reach saturation and allows us to suggest appearance of an eventual generation – recombination noise for high length, while α_H shows a linear increase with *L*.

Many spectra are obtained at different temperatures, and fitted by the Hooge's expression to study the temperature and the field effects on γ and α_H. Fig. 4 gives γ as a function of temperature *T*.

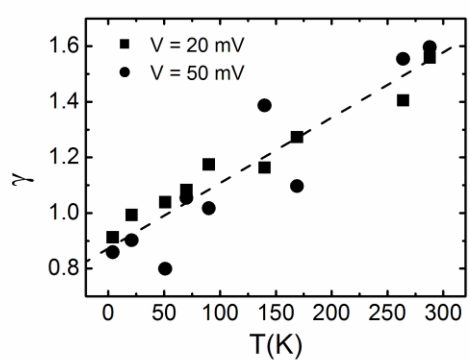

Fig.4. Linear increase of γ with temperature. The applied bias effect on γ is not obvious.

The γ increases monotonically as ~ $0.87 + 2.3\times10^{-3}\times T$ with T from ~ 0.87 up to ~ 1.6 indicating at least two processes; gradual change in the nature of the noise from *1/f* to likely Lorentzian. This is consistent with previous studies wherein it was suggested that the presence of Lorentzian noise at very low frequency was due to the shift of some existing *G-R* noise [7, 8].

We also expect appearance of a new Lorentzian noise which was screened at low temperature. Occurrence of Lorentzian noise is linked to carrier exchange and we think that this happened at the GaAs spacer layer interfaces leading to carrier density reduction when the temperature decreases and not between the GaAs quantum well and doping impurities since these latter are "confined" in an AlGaAs layer in form of δ-doping beyond the spacer layer as quoted above. On the other hand, γ does not show noticeable dependence on the applied voltage. Fig. 5 gives α_H as a function of temperature.

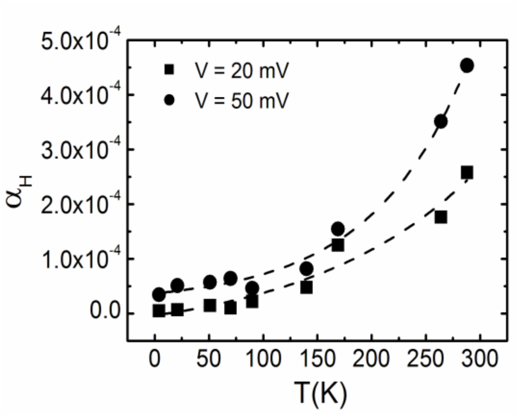

Fig.5. Increase of α_H with temperature. Experimental points are well fitted by ~exp(T/T_0) dependently on the applied bias.

α_H increases exponentially with temperature as ~ exp(T/T_0) where T_0 is affected by the applied voltage value (~90 K at 50 mV and ~154 K at 20 mV). Experimental α_H values stand lower than the empirical value $\alpha_H = 2\times10^{-3}$ found experimentally by Hooge in 1969 [9] and linked to $\alpha_{lattice}$ considered to be independent of the material. The lower values of α_H in our study are due to the fact that they are obtained in a 2DEG, and it was previously shown that the Hooge parameter $\alpha_{Hlattice}$ of the 2DEG structure does not correspond to $\alpha_{Hlattice}$ of undoped bulk material [10 - 12]. The α_H is also lower than the Handel value proposed for large samples and given by Handel's second (or coherent) equation, in terms of the mobility μ in the case of coherent state quantum *1/f* noise:~4.6×10^{-3} [13]. On the other hand, the α_H increase process is accompanied with increase of carrier density with temperature (from ~2×10^{11} cm^{-2} at 4 K up to ~6×10^{11} cm^{-2} at 300 K) and reduction of their mobility (from ~2×10^{6} cm^{2}V^{-1}s^{-1} at 4 K to up down ~3800 cm^{2}V^{-1}s^{-1}). This could indicate that the *1/f* noise would be in the fluctuations in the carrier density. Nevertheless, the GaAs channel, wherein the 2DEG is confined, is undoped and is free of defects. Moreover, the mobility reduction rate (~ 99 %) is higher than the density increase rate (~ 66 %) when the temperature increases. It was previously shown that the presence of impurities and defects in the GaAs channel lead to weak carrier mobility at low temperature [14, 15]. This is not the case in our sample. This allows us to suggest that the mobility fluctuations are dominated in the *1/f* noise.

To corroborate our assumption, we give in Fig. 6, the presentation in ln-ln scale of α_H as a function of the 2DEG mobility (μ) for some temperatures. The slopes are approximately close to 2 confirming the dominance of the lattice mobility fluctuations.

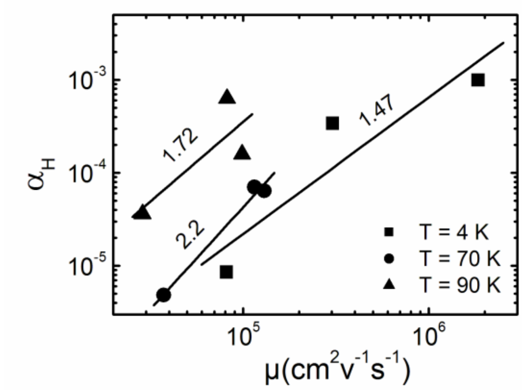

Fig.6. The ln(α_H) vs ln(μ) at three temperatures. The slope values are close to 2,
indicating the dominance of the lattice mobility in the flicker noise

IV. Conclusion

In summary, the *1/f* noise in a 2DEG has been characterized at different temperatures from 300 K down to 4 K and for two applied bias values. The temperature and field effects on the Hooge's parameters (γ and α_H) have been studied. γ was shown to linearly increase with the temperature independently of the field, while α_H varies as ~exp(T/T_0) depending on the applied bias amount. Increase of both parameters on the sample length has also been observed, showing saturation of γ to ~ 1.6, but a linear increase of α_H. All these variations suggest us that an eventual generation – recombination likely appears for high length and high temperature. The presentation in ln-ln scale of α_H as a function of μ gives slopes close to 2, suggesting that the origin of the *1/f* noise is related predominantly to the lattice mobility.

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