Low frequencies anomalies in GaAs FETs

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ABSTRACT

The activation energy and capture cross section of the traps founds in GaAs field Effect transistors (GaAs FETS) have been measured both in ohmic and saturation region. A variety of transients found using frequency dispersion, generation recombination noise techniques and DLTS techniques. The measure properties indicate that thermal emission from these traps is not a simple exponential. The transient differ from one trap to another and the location of each traps are influenced by the device structure.

Keywords: deep traps, g-r noise, DLTS, low frequency dispersion.

1 INTRODUCTION

After almost three decades of research and development, GaAs FETS integrated circuit has entered the commercial market place. The fascination of MESFET is its high frequency performance capability, which offers a complementary technology to other compound semiconductors. Perhaps the catalyst to the surge of commercial interest in GaAs FETS technology has been the introduction of mobile communication, semiconductor high density memory and other high frequency hand held devices. Nanostructure integrated circuits of MESFET have emerged as leading contenders for ultra-dense memory devices. Disadvantage of MESFETS is its sensitivity towards low frequency anomalies in modulation, analogue to digital conversion mechanisms and in other low frequency characteristics [1, 2]. Many well-known parasitic effects such as gate and drain lag effect, backgating effect, low frequency noise and other characteristics drift with deep level impurties [3] and thus limit the application of MESFETS devices for broad band applications. Several noise models exist for semiconductor devices. Small signal equivalent circuit models discussed by Gupta et al, [4] Podell [5] and Fukui [6] based on the need to improve the noise figure predictions. In these models, as expected, the minimum noise figure decreases monotonically with decreasing gate width in most of the device noise calculations. However the drain current, gain and output conductance also decrease. Thus for circuit application, selecting the optimal gate width for minimum noise figure of the device. In order to achieve a comprehensive model of noise, it is essential to study the deep level effects on MESFETS behaviour in detail. More detail on g-r noise and 1/f noise have been studied [7] in order to compare the results with the techniques like DLTS and low frequency dispersion [8, 9]. To study the defect levels in the GaAs FETs the capacitance DLTS technique is often not suitable since the capacitance of the gate-channel depletion region of these devices is very small. In these cases the transient is measured as the channel conductance mode of DLTS [10]. Electrical noise measurement systems are very powerful tools to investigate the theoretical and practical information about the material and the device. The 1/f drain noise is the usual characteristics [11] of GaAs FETs specimens, although it is affected by the presence of generation-recombination (g-r) component. The low frequency dispersion technique is equally powerful [12] and is used to identify the trapping effects in GaAs FETs.

In this paper the low frequency noise, DLTS and frequency dispersion measurement system was developed and measurement was carried out in Faraday cage to reduce external interference. Later, the computer software for theoretical analyzing, the experimental data was developed in order to correlate the results of different measurement techniques.

2 EXPERIMENTS

The systems that measure the DLTS rate window and the transient fitting procedure have been described [13]. The device is biased at a constant drain-source current I_{DS}. A voltage pulse is applied to the gate and the resulting transient of the drain-source voltage, $V_{DS}(t)$, due to the emission by the trap is measured using an A/D converter. The transient can be studied at a constant temperature by changing the pulse bias levels. In this system it is also possible to study the transient $V_{DS}(t)$ at fixed temperature. The experimental data of the measured transient are fitted to the developed theoretical curve [14]. In the fitting procedure the least square method is used. In this method the best fitting parameters are selected by minimizing the sum of the squares of the difference between the fitting curve and the experimental data.

$$G_{DS} = \frac{I_{DS}}{V_{DS}} = \frac{V_{DD}-V_{DS}}{V_{DS}R_L} \tag{1}$$

The noise measurements include the parameters V_{DS}, V_{GS}, V_{bi}, V_{DD} and the load resistance (R_L). A dual channel spectrum analyser is used to convert a finite number of discrete samples of a time varying input signal into a discrete frequency spectrum. In the excess noise measurements the square-root of the power spectrum is used and the observed noise spectrum is plotted $(V_n^2\times f)/\Delta f$

against log(f). It has been observed that the transconductance in GaAs FETs varies with frequency [15]. Measurement of g_M has been carried out over the frequency range 0.4 Hz to 25 kHz using the Amplitude Transfer Function measurement capabilities of the dual channel spectrum analyser with a white noise input. Cancellation circuits were modified and developed [16] to enhance the sensitivity of the method. The g_M results were obtained using the equation of the form:

$$g_M = \frac{ATF}{R_f} \tag{2}$$

where R_f is the feedback resistance of the drain current to voltage converter and ATF is the amplitude transfer function. The specimens used are low noise commercial devices. Two batches, each consists of the group name and the number. These devices have 0.5 μm gate length and have a bandwidth of 8 GHz at 13 dB gain.

3 RESULTS AND DISCUSSION

Gate DLTS were performed on several GaAs FETs of each batch by pulsing the gate and keeping I_{DS} constant. The gate DLTS spectrum of the digitally acquired transient using different rate-windows are shown in Fig.1

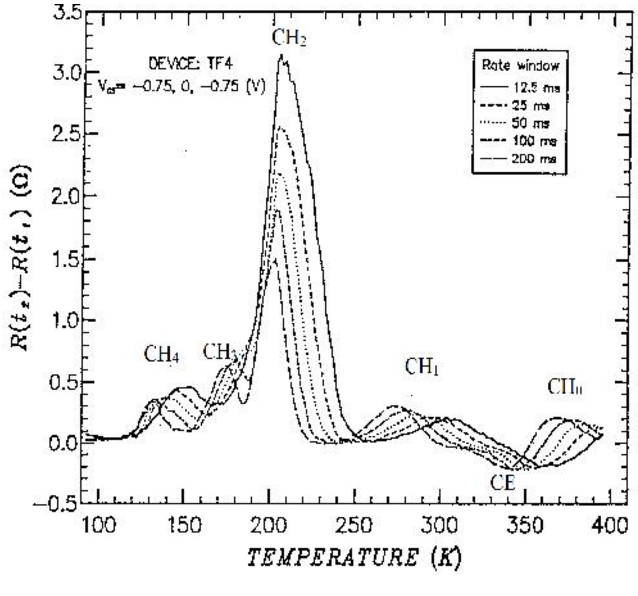

Figure 1: DLTS spectra at V_{DS} = 0.1 V.

Five hole traps CH5, CH4, CH3, CH2, and CH0 are observed in almost all devices with different concentration. In the observed spectra the hole-like trap CH3 dominates and the presence of an electron-like trap CE2 distorts the spectrum. The finding of Iqbal [17] are using time dependent properties, concluded that CH2 and CH5 are located at the free surface between the gate and source or drain and CH3, CH4 and CH0 are substrate traps located at the channel-substrate interface.

A study has been carried out on each device for which the rate window temperature spectra are similar to Fig 1. We concentrate on each set of peaks of traps appearing at different temperatures. We selected 360 K in order to obtain a convenient time constant for the CH0 trap. A fit is made and the transient S(t) and the fitting curves are shown in Fig 2. This trap is best fitted to an interface trap assumption [18].

$$S(t) = A_0 + A\left[1+e^{-t/\tau}\right]^{1/2}. \tag{3}$$

where A is the conductance transient amplitude and A_0 is the term that has to be added in the presence of any apparatus drift and possible slow transient.

τ_1 (ms)	A_1 10^{-3}	τ_2 ms	A_2 10^{-3}	τ_3 ms	A_3 10^{-3}	A_0	Q
82.6	4.08					.126	9.5
128	2.97	13.7	2.15			.026	3.8
152	2.44	33.1	1.68	5.32	1.26	.001	1.9

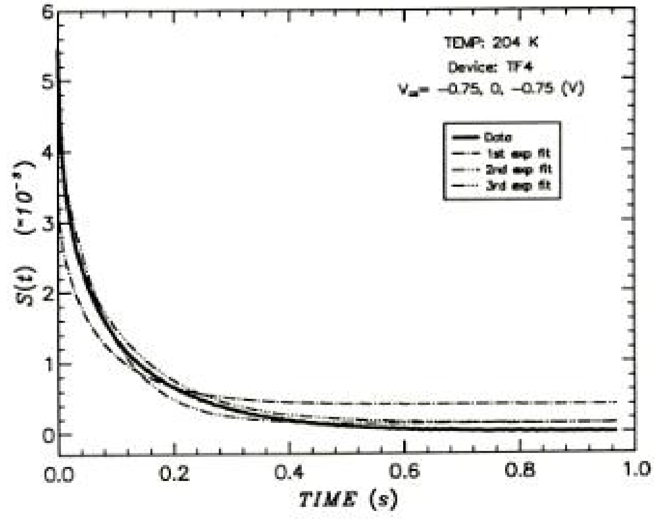

Figure 2: Transient S(t) and the fitting curves

This fitting shows that the transient due to an interface trap in GaAs FETs is not a simple exponential but gives best fit using equation 3. The CH3 trap at 199 K and CH4 trap at 175 K were selected and the observed results are fitted to equation 3. These fitting results are reasonably good. Moreover each of these traps (CH4, CH3, CH0) were again fitted to a simple exponential equation.

$$S(t) = A e^{-t/\tau} + A_0 \tag{4}$$

The activation energy of each trap is calculated using an Arrhenius plot and the observed values are presented in Table 1. This is referred to the qualitative model suggested by Rocchi et al [19]. For simplicity we make the following assumption. Since a voltage applied to the gate is found to modify the population of traps located near the channel-substrate interface then we assume that a potential drop exists at this interface. This potential drop implies the existence of the space-charge region and this is the right condition for traps to change their population. The bias [20] and the time dependent [21] measurements also confirm that these traps are related to the non-gated region of the active channel. A surface trap model is used to characterize the CH5 and CH2 traps.

Low frequency excess noise [22] was measured at various fixed temperature between the range 77 K to 400 K (on the same devices) and the observed g-r noise spectra in the ohmic channel was fitted to the equation,

$$S_i(f) = \sum_{i=1}^{m} \frac{A_i \omega \tau_i}{1+(\omega\tau_i)^2} + B \qquad (5)$$

Where A_i and τ_i are the amplitudes and the time constants of the ith g-r peak.

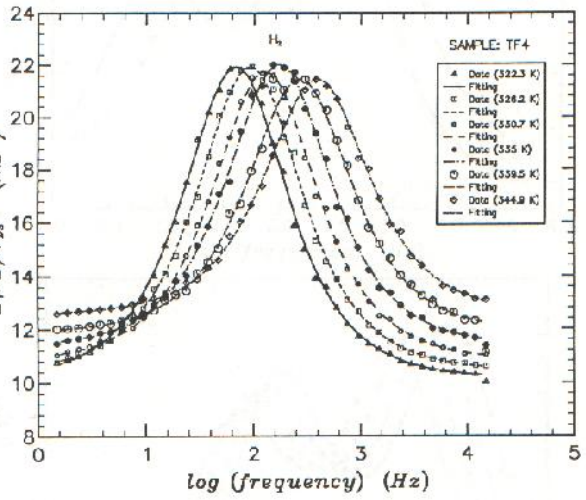

Figure 3: g-r noise data and fitting results.

The g-r noise is thermally stimulated, therefore the value of the activation energy and the cross-section were evaluated by using the equation.

$$\tau = \frac{\tau_0}{\sigma \times T^2} \exp\left[\frac{E_a}{kT}\right] \qquad (6)$$

Where E_a is the activation energy of the trap, σ is the capture cross-section of the trap and τ_0 is constant. An example of g-r noise fitting for the NH2 is illustrated in Fig.3. The activation energy of the CH4 trap is calculated using the Arrhenius plot and the result of these traps are presented in Table 1. We will discuss the electron trap NE1 elsewhere in more detail when we consider the electron traps in detail.

The experimental data of the g_M frequency dispersion is fitted to one or more theoretical modified form of the Debye equation,

$$g_M(\omega) = \sum_{i=1}^{m} \frac{(\Delta g_M)_i}{1+(\omega\tau_i)^2} + g_h \qquad (7)$$

where $(\Delta g_M)_i$ is the magnitude of the i_{th} g_M dispersion and τ_i is the time constant. An example of low frequency transconductance fitting for the gH3 trap is illustrated in Fig 4. The transconductance methods also confirm the presence of the gH3 trap.

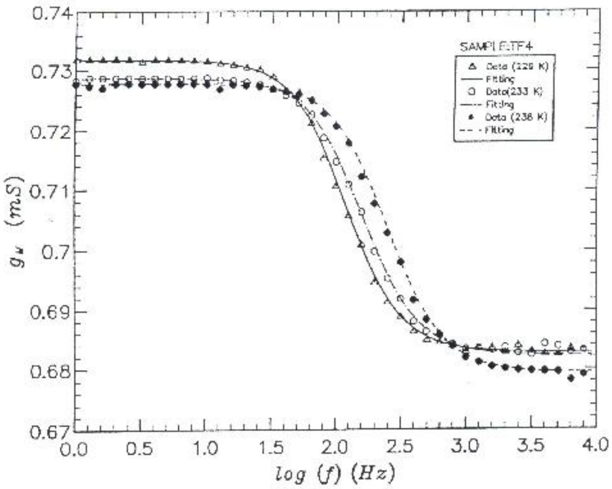

Figure 4: Low frequency g_M dispersion results at different temperatures.

The trapping signature of gH3 is the same as the CH3 trap within the experimental error. The activation energy of the trap is calculated using the Arrhenius plot and the result of these traps are presented in Figure 5. The number of traps observed by the trans-conductance technique are small as compared to DLTS and g-r noise, therefore the observed results indicate that the low frequency dispersion technique is shown to be less effective compared with the DLTS method.

The trap signature observed by the g_M dispersion technique is presented in Table 1. The facts conclude that using this method the dispersion technique is only capable of revealing traps with large magnitude, unlike the g-r noise technique.

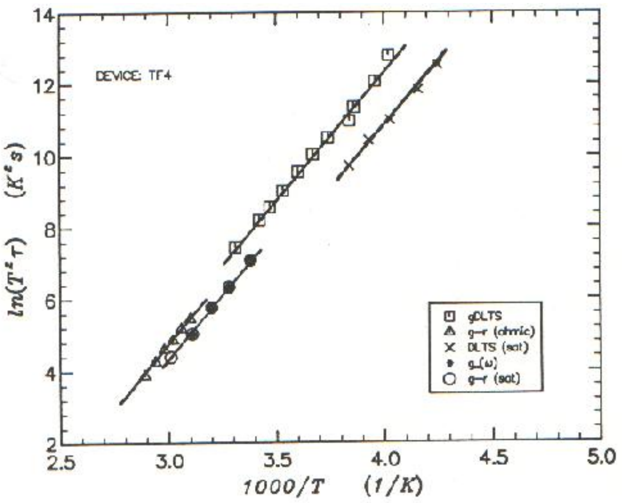

Figure 5: The Arrhenius plot of time constants evaluated at different temperatures.

Reliability is a core feature that can make or break the long term success of both product and companies. Simple scaling arguments show that the above problems will get more importance as device become smaller.

Trap Label	ΔE (eV)	Location in device structure	Characterization method used
CH0	0.934	channel-substrate	Gate DLTS
CH2	0.662	surface	Gate DLTS
NH2	0.628	surface	g-r noise
CH3	0.451	channel-substrate	Gate DLTS
NH3	0.448	channel-substrate	g-r noise
gH3	0.436	channel-substrate	g_m dispersion
CH4	0.352	channel-substrate	Gate DLTS
CH5	0.137	surface	Gate DLTS

Table 1: Summary of the observed traps

4 CONCLUSIONS

In DLTS, g-r noise and dispersion measurements on the various traps show approximately the same characteristic time as that of the capture and emission process. The observed activation energies are almost same, within the experimental error. The fact revealed above, leads with great certainty, to the conclusion that the trap levels associated with the hole traps are not real hole traps of the active channel. On the other hand, the excess g-r noise method is shown to be more effective in the closely spaced traps within a small temperature range. The other hole traps at high temperatures are almost impossible to study as these traps appear beyond the maximum recommended temperature of these devices. The low frequency dispersion technique can be considered as an alternative to DLTS, although dispersion method is found to be more sensitive to traps existing in the active channel.

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