HIGH FREQUENCY EXCESS NOISE AND FLICKER NOISE IN GaAs FETs

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Abstract—The noise parameter \( \alpha = R_{\text{eq}}g_m \), where \( R_\alpha \) is the noise resistance and \( g_m \) the transconductance, was measured for \( n \)-channel GaAs FETs. At lower frequencies \( \alpha \) varies as \( 1/f \), as expected for flicker noise, whereas at higher frequencies \( \alpha \) attains a limiting value \( \alpha_\infty \) that is larger than expected for thermal noise. Arguments are presented to show that the high-temperature value of \( \alpha_\infty \) is due to a geometry effect, possibly aided by a temperature-independent hot electron effect, whereas the low-temperature data reflect a temperature-dependent hot electron effect. The flicker noise is practically temperature independent, and is attributed to the large interface between semiconductor and oxide.

It is the aim of this note to report on high-frequency noise measurements on GaAs FETs, which indicate the presence of hot electron noise effects, and give some information about \( 1/f \) noise in these devices.

In the discussion the noise is expressed in terms of the noise parameter \( \alpha \), defined as

\[
\alpha = \frac{2eL_{\text{eq}}}{(4kT_g)} = R_{\text{eq}}g_m
\]

where \( g_m \) is the device transconductance, \( R_\alpha \) the equivalent noise resistance at the input, \( L_{\text{eq}} \) the equivalent saturated diode current at the output, \( e \) the electron charge, \( k \) Boltzmann's constant and \( T \) the absolute temperature of the device.

At lower frequencies \( \alpha \) varies as \( 1/f \), indicating the presence of flicker noise, and at high frequencies \( \alpha \), \( L_{\text{eq}} \) and \( R_{\text{eq}} \) approach limiting values \( \alpha_\infty \), \( L_{\text{eq}} \), and \( R_{\text{eq}} \), respectively, due to thermal noise that includes hot electron effects, especially at lower temperatures.

For long channel devices, in which the gate extends over the whole channel length \( \alpha_\infty \) has the value of about \( 2/3 \), as shown by van der Ziel[1], but for short channel devices in which the gate covers only a small part of the channel, as in most GaAs FETs, \( \alpha_\infty \) will be somewhat larger, even if no hot electron effects are present (geometry effect). When hot electron effects do exist, \( \alpha_\infty \) becomes considerably larger and increases with decreasing temperature \( T \).

The GaAs FETs under test were experimental devices provided by Bell Laboratories. The drain current could be varied up to 30 mA; the drain voltage was kept relatively low to avoid overheating.

Figure 1 shows \( \alpha \) as a function of frequency for a typical sample, operating at a drain current of 15 mA and a drain voltage of 1.5 V, with the temperature \( T \) as a parameter. We see that at low frequencies \( \alpha \) has a \( 1/f \) spectrum that depends only slightly on temperature, whereas at high frequencies \( \alpha \) approaches a limiting value \( \alpha_\infty \) that increases with decreasing temperature. We come back to this in a moment.

Figure 2 shows first \( L_{\text{eq}} \) at \( T = 77^\circ \text{K} \) and a frequency of 25 MHz, where the noise is frequency independent, at \( V_d = 1.5 \text{ V} \) as a function of the drain current \( I_d \). We note that the curve is practically linear, which is probably accidental; we need it for the interpretation of \( \alpha_\infty \) as a function of \( I_d \).

Figure 2 also shows \( \alpha_\infty \) as a function of \( I_d \) at \( T = 77^\circ \text{K} \) and \( V_d = 1.5 \text{ V} \). We see that \( \alpha_\infty \) increases with increasing current, as expected for hot electron effects[2]. At low

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currents, however, $\alpha_m$ increases with decreasing $I_d$, so that $\alpha_m$ has a minimum value at a particular value of $I_d$. This is probably a consequence of the impurity profile of the conducting channel near the semi-insulating substrate. The effect would be reduced by aiming for a constant impurity profile that drops sharply to zero at the interface with the substrate; this would result in a decrease in $\alpha_m$ at low drain current, which, in turn, would have a beneficial effect on the microwave noise figure of the FET.$^1$

Figure 3 shows $\alpha_m$ at $I_d = 15$ mA as a function of $e/kT$. We see that $\alpha_m$ is practically constant at temperature below 193°K and increases sharply with decreasing temperature below that temperature. This is in agreement with other experiments.$^3$.

We believe that the temperature independence of $\alpha_m$ at higher temperatures is chiefly a geometry effect, perhaps helped by a temperature-independent hot electron effect, whereas the low-temperature phenomena are due to a temperature-dependent hot electron effect. If the low-temperature phenomena were due to generation-recombination noise, $\alpha_m(T) - \alpha_m(300)$ would vary as $\exp(eE_s/kT)$, where $E_s$ is the activation energy of the $g - r$ noise process, usually caused by donors or traps.$^4$. Hence when $\alpha_m(T) - \alpha_m(300)$ were plotted vs $e/kT$, one would obtain a straight line. Figure 3 shows that this is not the case and hence the $g - r$ noise hypothesis must be discarded. This leaves only the hot electron noise hypothesis as a viable explanation of the data.

Baechthold$^5$ has proposed that the electron temperature $T_e$ may be written

$$T_e/T_0 = 1 + \delta(E/E_s)^3$$

where $T_0$ is the lattice temperature, $E$ the field strength, $E_s$ the saturation field strength, and $\delta$ a field-independent parameter that may depend on temperature. Our data indicate that $\delta E_s^3$ must increase strongly with decreasing temperature at low temperatures. There are too many parameters in the expression to determine $T_e$ and $E_s(T)$ individually.

The low-frequency noise is flicker noise. As is seen from Fig. 1, the low-frequency value of $\alpha$ does not depend very much upon temperature. If one converts from $\alpha$ to the equivalent input noise resistance $R_n$, with the help of eqn (1), one obtains approximately the same temperature dependence for $R_n$, since $\alpha_m$ does not depend very much on temperature either.

Silicon JFETs have practically no flicker noise. Since they also have practically no semiconductor-oxide interface, this has led to the conclusion that the source of 1/f noise in semiconductors is located in the semiconductor-oxide interface.$^6$. Since the GaAs FET has an open structure with a very narrow gate, it has a large semiconductor-oxide interface area; it is therefore not surprising that it shows an appreciable amount of flicker noise. Because of the peculiar geometry, an exact theory of 1/f noise in GaAs FETs would be difficult to develop.

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Fig. 3. $\alpha_m(T)$ taken from Fig. 1, replotted as a function of $e/kT$. Also shown is $\alpha_m(T) - \alpha_m(300)$. 
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REFERENCES
4. Compare, e.g. A. van der Ziel, Noise in Measurements, Chap.