the hybrid transistor, which alleviates the contradiction between the current gain and the breakdown voltage. The detailed quantitative analysis will be reported in the future.

IV. Conclusion

A new SOI drive-in gate controlled hybrid transistor (DGCHT) is presented in this paper. The current gain of the DGCHT is 10 000. The subthreshold swing is 90 mV/dec, with the switching-on voltage of 0.58 V. It can be shown experimentally that the Early effect is lowered in DGCHT despite of the short channel length and the depleted base surface, and the breakdown voltage is increased despite of the high current gain. The contradiction between the current gain and the breakdown voltage in conventional BJT can be alleviated in DGCHT due to its operating mechanism, making the device design more flexible. With the good experimental characteristics, DGCHT can be suitable to high speed and analog applications.

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References

[1] J. P. Colinge, "A SOI voltage-controlled bipolar-MOS device," *IEEE Trans. Electron Devices*, vol. 34, pp. 845–851, Apr. 1987.
[2] S. A. Parke, C. Hu, and P. K. Ko, "Bipolar-FET hybrid-mode operation of quarter-micrometer SOI MOSFET's," *IEEE Electron Device Lett.*, vol. 14, pp. 234–236, 1993.
[3] S. Verdonckt-Vandebroek, S. S. Wong, J. C. S. Woo, and P. K. Ko, "High-gain lateral bipolar action in MOSFET structure," *IEEE Trans. Electron Devices*, vol. 38, pp. 2487–2496, Nov. 1991.
[4] F. Assaderaghi, D. Sinitsky, S. A. Parke, J. Bokor, P. K. Ko, and C. Hu, "Dynamic threshold-voltage MOSFET (DTMOS) for ultra-low voltage VLSI," *IEEE Trans. Electron Devices*, vol. 41, pp. 414–422, Mar. 1997.
[5] G. G. Shahidi *et al.*, "CMOS scaling in the 0.1-μ m, 1.x-volt regime for high performance applications," *IBM J. Res. Develop.*, vol. 39, no. 1/2, pp. 229–242, Jan./Mar. 1995.
[6] Z. Parpia and C. A. Salama, "Optimization of resurf LDMOS transistors: An analytical approach," *IEEE Trans. Electron Devices*, vol. 37, pp. 789–795, Apr. 1990.
[7] R. Huang, Y. Y. Wang, and R. Q. Han, "Analytical model for collector current in SOI gate controlled hybrid transistor," *Solid State Electron.*, vol. 39, pp. 1816–1818, Dec. 1996.
[8] ——, "A piecewise model for collector current in the SOI gate controlled hybrid transistor," to be published.

Influence of Al Mole Fraction on the Noise Performance of GaAs/Al$_x$Ga$_{1-x}$As HEMT's

Javier Mateos, Daniel Pardo, Tomás González, Patrick Tadyszak, François Danneville, and Alain Cappy

***Abstract*—By using a Monte Carlo particle simulation, the influence of the Al mole fraction on the intrinsic noise properties of GaAs/AlGaAs HEMT's is analyzed. P, R, and C noise parameters and the minimum intrinsic noise figure are calculated. The results reveal that the decrease of the energy barrier at the heterojunction as the Al mole fraction is reduced (which leads to a closer approach of the electrons to the gate electrode) makes the noise associated to this electrode increase, consequently degrading the noise performance of the device.**

***Index Terms*—GaAs/AlGaAs devices, HEMT, modeling, Monte Carlo method, noise.**

I. Introduction

Low-noise high-frequency applications of high electron mobility transistors (HEMT's) make necessary an exhaustive characterization of their dc, ac, and noise properties. The Monte Carlo technique, by including all the microscopic details of carrier transport, is very well suited to this end. While the static characteristics of HEMT's have been widely analyzed by using this technique [1]–[3], very few attempts have been made to study their dynamic and noise behavior [4], [5].

An issue of special interest in the performance of these devices is the influence of the Al mole fraction X_{Al}. This parameter controls the conduction-band edge discontinuity at the heterojunction and therefore the confinement and electron density in the GaAs channel. A high value of X_{Al} is desirable. However, when values beyond 0.20 are reached several problems related to the presence of DX centers appear. A detailed characterization of the influence of the Al mole fraction on the static characteristics of HEMT's can be found in [3]. In this brief we report the effect of X_{Al} on their intrinsic noise performance by reducing its value from 0.20 to 0.10 and 0.05, thus completing the analysis of the device performed in [5]. The results show that the reduction of the Al mole fraction degrades the noise behavior of HEMT's.

II. Model and Noise Calculation

A schematic drawing of the simulated HEMT is shown in Fig. 1(a). The geometry and doping of the device have been chosen to reproduce the behavior of a previously fabricated and analyzed ungated structure [4]. The aspect ratio is low, 3.6, which means that short-channel effects will be present. Three different values of the Al mole fraction have been analyzed: 0.05, 0.10, and 0.20. A semiclassical ensemble

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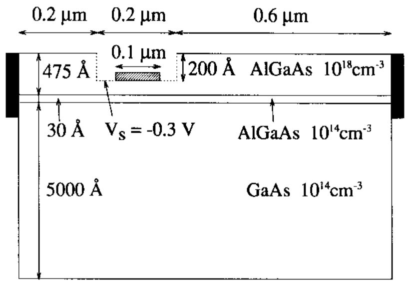
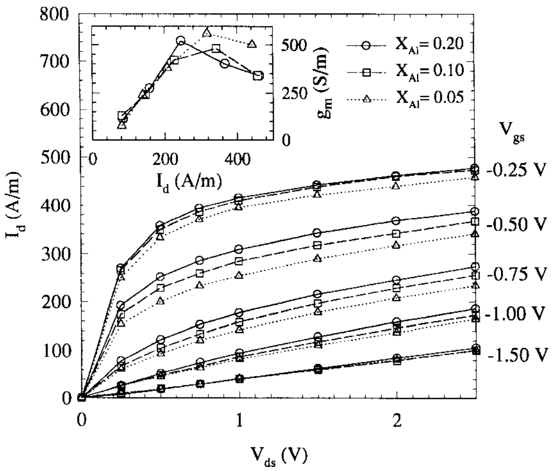


(a)



(b)

Fig. 1. (a) Scheme and (b) I_d–V_{ds} characteristics of the simulated HEMT's (the inset shows the low frequency value of the transconductance for $V_{ds} = 2.0$ V). The gate voltages include the built-in potential of the Schottky contact.

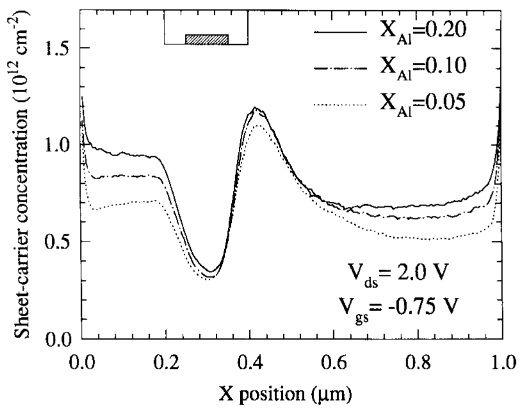


Fig. 2. Sheet-carrier concentration in the GaAs layer of the HEMT's with $X_{\rm Al} = 0.20$ (solid line), $X_{\rm Al} = 0.10$ (dash-dot line) and $X_{\rm Al} = 0.05$ (dotted line). The biasing is $V_{ds} = 2.0$ V and $V_{gs} = -0.75$ V.

Monte Carlo simulator coupled with a two-dimensional Poisson solver is used for the analysis. The details of the model used to simulate the HEMT can be found in [4]–[6].

The determination of noise performance involves both the small-signal analysis of the device and the evaluation of the intrinsic noise sources [7]. The small signal characterization is based on the calculation of the Y parameters through the Fourier analysis of the transient behavior of the HEMT when a voltage step is applied to the gate or drain electrode [8]. As noise sources, the spectral densities of the drain- and gate-current fluctuations and its cross-correlation are calculated (S_{i_d}, S_{i_g}, and $S_{i_g i_d}$, respectively) [9]. From both the Y parameters and the noise sources, the dimensionless noise parameters P, R, and C [7], [10], and the intrinsic minimum noise figure F_{int} [11] are extracted. The details of this analysis can be found in [5].

III. Results

The I–V characteristics of the simulated structure for the three values of $X_{\rm Al}$ are shown in Fig. 1(b). When $X_{\rm Al}$ is diminished, the energy barrier at the heterojunction passes from 0.145 eV at $X_{\rm Al} = 0.20$ to 0.070 eV at $X_{\rm Al} = 0.10$, and to 0.034 eV at $X_{\rm Al} = 0.05$. Hence the accumulation (in the GaAs) and depletion (in the AlGaAs) layers near the heterojunction are less pronounced. This effect can be observed in Fig. 2, which shows the sheet-carrier concentration in the GaAs accumulation layer (calculated by adding all the carriers present at each y position in the GaAs layer) for the previously mentioned values of $X_{\rm Al}$. It is also observed how the accumulation domain effect at the drain side of the gate is less important as $X_{\rm Al}$ decreases [3]. Fig. 1(b) shows how the decrease of $X_{\rm Al}$ leads to lower values of the drain current due to the poorer confinement of carriers in the GaAs layer, this effect being more pronounced for intermediate values of the gate potential, for which the current flow takes place mainly in the GaAs accumulation layer. For the lowest values of V_{gs} (-1.0 V, -1.5 V) practically no difference between the three values of $X_{\rm Al}$ is detected, since the current flows in the GaAs layer far from the heterojunction, where the value of $X_{\rm Al}$ has no influence. In the case of $V_{gs} = -0.25$ V, most of the current flows through the top AlGaAs layer, and again similar values of I_d are observed. The transconductance g_m for $V_{ds} = 2.0$ V, shown in the inset of Fig. 1(b), reflects the behavior of the I–V characteristics previously explained. The most significant differences take place for intermediate values of the drain current, where the peak of g_m appears. The position of the peak moves to higher I_d as $X_{\rm Al}$ decreases due to the lower concentration of carriers in the GaAs accumulation layer (Fig. 2). The evolution with I_d of the current gain cutoff frequency f_t, another important parameter in the ac performance of the device, follows a very similar behavior to that explained for g_m.

The P, R, and C noise parameters, together with F_{int}, are presented in Fig. 3 as a function of the drain current for the three values of $X_{\rm Al}$ and for $V_{ds} = 2.0$ V. P, R, and C show no significant frequency dependence up to 100 GHz. F_{int} is shown at two frequencies: 10 and 100 GHz. Due to the high uncertainty in the Monte Carlo calculation of the noise parameters [5], they do not show a clear dependence on I_d. To enlighten this dependence we have fitted the results to a parabolic curve in the case of P and F_{int} (in agreement with the typical "U" dependence found theoretically [7], [12]) and to a straight line in the case of R and C (showing the trend of the data). It can be observed that P and C take similar values for the three Al mole fractions, but an increase of R as $X_{\rm Al}$ is reduced is noticed. This is an expected effect, since the lower energy barrier at the heterojunction allows the electrons to transfer more easily to the top AlGaAs layer and so to approach the gate, thus increasing the noise associated to this electrode, which is reflected in the parameter R. F_{int}, by following the behavior of the cutoff frequency, reflects a similar dependence to that of the transconductance: the minimum moves to higher I_d when $X_{\rm Al}$ is lowered. In order to achieve low-noise and high-gain performance of the HEMT, the optimum operation point must be a tradeoff between low F_{int} and high g_m. In our case, the optimum operation point coincides with the minimum of F_{int}, since the gain, even if it is not the best, is not much degraded. The effect of the increasing gate noise will be also present in the minimum value of F_{int}, which gets higher

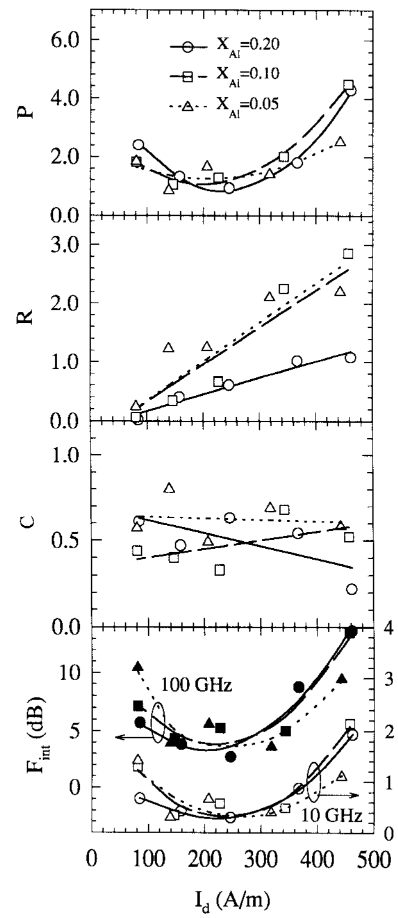


Fig. 3. P, R, and C parameters and F_{int} (for two frequencies, 10 GHz, open symbols, and 100 GHz, close symbols) of the HEMT's with: $X_{\rm Al} = 0.20$ (circles, full lines), $X_{\rm Al} = 0.10$ (squares, dashed lines), and $X_{\rm Al} = 0.05$ (triangles, dotted lines) as a function of I_d for $V_{ds} = 2.0$ V. The lines correspond to the fitting of the data to a parabola in the case of P and F_{int} and to a straight line in the case of R and C.

at lower $X_{\rm Al}$. This growth of the gate noise results not only from the decrease of $X_{\rm Al}$ (which deteriorates R for every bias), but also because of the displacement to higher I_d of the optimum operation point (where R grows). Therefore, the electron confinement in the GaAs channel must be improved to optimize the noise properties of the HEMT.

IV. Conclusion

We have analyzed the dependence of the intrinsic noise behavior of GaAs/AlGaAs HEMT's on the Al mole fraction. An increase of the noise at the gate is detected as $X_{\rm Al}$ is reduced, due to the lower energy barrier at the heterojunction, which makes easier for the carriers to approach the gate. It is also detected that the peak of the transconductance moves to higher gate voltages (and also the F_{int} minimum) as $X_{\rm Al}$ is lowered and, consequently, the optimum operation point is found at higher I_d, which leads to a higher noise figure (because of the greater gate noise). Therefore, the confinement of carriers in the GaAs channel must be optimized in order to get a high-power low-noise device by taking a value of $X_{\rm Al}$ as large as the technological limits allow.

References

[1] K. W. Kim, H. Tiang, and M. A. Littlejohn, "Analysis of delta-doped and uniformly doped AlGaAs/GaAs HEMT's by ensemble Monte Carlo simulations," *IEEE Trans. Electron Devices*, vol. 38, p. 1737, 1991.

[2] G. U. Jensen, B. Lund, T. A. Fjeldly, and M. Shur, "Monte Carlo simulation of short-channel heterostructure field-effect transistors," *IEEE Trans. Electron Devices*, vol. 38, p. 840, 1991.

[3] I. C. Kizilyalli, M. Artaki, and A. Chandra, "Monte Carlo study of GaAs/Al$_x$Ga$_{1-x}$As MODFETs: Effects of GaAs/Al$_x$Ga$_{1-x}$As composition," *IEEE Trans. Electron Devices*, vol. 38, p. 197, 1991.

[4] J. Mateos, T. González, D. Pardo, P. Tadyszak, F. Danneville, and A. Cappy, "Noise and transit time in ungated FET structures," *IEEE Trans. Electron Devices*, vol. 44, p. 2128, 1997.

[5] ——, "Noise analysis of 0.1 μm gate MESFET's and HEMT's," *Solid-State Electron.*, vol. 42, p. 79, 1998.

[6] ——, "Numerical and experimental analysis of static characteristics and noise in ungated recessed MESFET structures," *Solid-State Electron.*, vol. 39, p. 1629, 1996.

[7] A. Cappy, "Noise modeling and measurement techniques," *IEEE Trans. Microwave Theory Tech.*, vol. 36, p. 1, 1988.

[8] T. González and D. Pardo, "Monte Carlo determination of the intrinsic small-signal equivalent circuit of MESFET's," *IEEE Trans. Electron Devices*, vol. 42, p. 605, 1995.

[9] T. González, D. Pardo, L. Varani, and L. Reggiani, "Monte Carlo analysis of the behavior and spatial origin of electronic noise in GaAs MESFET's," *IEEE Trans. Electron Devices*, vol. 42, p. 991, 1995.

[10] R. A. Pucel, H. A. Haus, and H. Statz, "Signal and noise properties of gallium arsenide microwave field-effect transistors," *Adv. Electr. Electron Phys.*, vol. 38, p. 195, 1975.

[11] A. Cappy, A. Vanoverschelde, M. Schortgen, C. Versnaeyen, and G. Salmer, "Noise modeling in submicrometer-gate two-dimensional electron-gas field-effect transistors," *IEEE Trans. Electron Devices*, vol. 32, p. 2787, 1985.

[12] B. H. Klepser, C. Bergamaschi, M. Schefer, C. G. Diskus, W. Patrick, and W. Bächtlod, "Analytical bias dependent noise model for InP HEMT's," *IEEE Trans. Electron Devices*, vol. 42, p. 1882, 1995.

Optically Induced Sidegating Current Isolation of GaAs MESFET by Multiquantum Barrier

Ching-Ting Lee

***Abstract*—The multiquantum barrier buffer layer in GaAs MESFET configuration exhibits great reduction on the optically induced sidegating current. The electrical and optically induced sidegating current suppressions of enhanced potential barrier height achieved with multiquantum barrier buffer layer are clearly demonstrated.**

***Index Terms*— Metal–semiconductor field effect transistors, multiple quantum barrier, semiconductor device.**

I. Introduction

To reduce the parasitic interaction of monolithic integrated circuits, the potential barrier height between the active channel and buffer layers must be large enough to provide better isolation. The multiple quantum barrier (MQB) structure has exhibited novel property and ability of increasing the potential barrier height [1], [2]. Recently, the

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