GAAS® 97 • 5th European Gallium Arsenide and related III-V compounds Applications Symposium
Bologna, Italy - September 3rd-5th, 1997

Effects of implanted carbon-buried p-layer on the performance of multifunction self-aligned-gate (MSAG) GaAs MESFET's

F. Fumi*, M. Peroni*, C. Lanzieri*, S. Donati Guerrieri†, M. Pirola†, F. Bonani†, and C. U. Naldi†

* *ALENIA un'Azienda Finmeccanica, Direzione Ricerche, GaAs Integrated Circuits, 00131 Roma, Italy*

†*Dipartimento di Elettronica, Politecnico di Torino, C.so Duca degli Abruzzi 24, 10129 Torino, Italy*

Abstract

This paper presents a new technology for the realization of multifunction self-aligned-gate GaAs MESFET's (SAGFET) through multiple implantation of silicon and carbon. The carbon different behaviour as shallow or deep acceptor as a function of annealing parameters and fluorine co-implantation is discussed and evidence is given that, being a carbon buried layer effective for carrier confinement in the active channnel, DC and RF performances can be considerably improved with respect to ordinary recess-gate MESFET's both for power and low-noise devices.

1. Process description

Selective implantation of $^{28}Si^+$ and $^{12}C^+$ in GaAs was used to realize the active channels of multifunction (low-noise and power applications) self-aligned MESFET devices. Silicon and carbon channel implantations were activated by rapid thermal annealing (RTA) before gate formation. A thin WN_X and a thick Au films were then sputter-deposited on the entire wafer, and the masking gate geometry was defined on the Au cap through ion milling. After the $^{28}Si^+$ self-aligned (n^+) implantation and RTA, the WN_X layer was removed by anisotropic CF_4+O_2 reactive ion etching. Source and drain contacts were formed by Au/Ge/Ni alloying. To increase the gate-drain breakdown voltage and reduce the gate junction capacitance, a low resistance, T-shaped gate structure was formed by means of a CF_4+O_2 etching of the WN_X layer [1]. A standard technology was then used to complete the multifunction devices and MMIC's (Figure 1).

Carbon was chosen for maximum long-term stability of the devices due to its very low diffusivity in GaAs. As will be shown, in spite of the well known low activation efficiency of implanted carbon as a shallow acceptor, a carbon buried layer is very effective for carrier confinement in the active channel, allowing for the realization of high performance SAGFET devices. Extensive investigation concerning carbon activation in GaAs [2] for different implantation doses, energies and also F^+ co-implantation dose were performed (SIMS, Hall and DLTS measurements). They showed the presence of a deep level at 0.48 eV above the valence band in addition to the usual shallow level so that a proper choice of the annealing process and F^+ dose can activate carbon either as shallow or deep acceptor (Figure 2): in both cases, the presence of a buried layer turns out to be active in carrier confinement, as confirmed by measurements and simulations.

2. Experimental results and comparison with numerical simulations

Both power and low-noise devices [2] showed DC performances comparable to those of standard recessed-gate MESFET's if no buried layer was added to SAGFET's, e.g. I_{DSS}=280 mA/mm, V_{PO}=4.5 V for power application devices, and I_{DSS}=180 mA/mm, V_{PO}=2.0 V for low-noise devices. Besides, measurements performed at 12 GHz confirmed the similar behaviour of SAGFET's without buried layer and recessed-gate MESFET's in terms of maximum power (500 mW/mm) and minimum noise (NF_{MIN} = 2 dB), even if a lower power added efficiency (PAE) and 1 dB lower associated gain was observed in SAGFET's because of the poor carrier confinement in the channel.

The introduction of implanted carbon allowed to realize SAGFET's with a considerably higher DC transconductance and drain current as reported in Figure 3 for low-noise devices (without (A) and with the buried carbon implanted layer (B)); concerning power SAGFET's, Idss=400 A/mm and V_{PO}=3.5 V were found.

The better carrier confinement in the channel, yields globally better RF performances: noise measurements gave NF_{MIN}=1.5 dB, while power devices showed a 35% PAE at 500 mW/mm, making our SAGFET technology a viable multifunction, low cost substitute of the traditional recessed-gate technology (Figure 4). In addition, the improved carrier confinement in the channel provided by the buried carbon doped layer allows to increase the n^+ implantation dose to reduce the intrinsic FET access resistances without introducing any serious short channel effect: end resistances measurements showed R_S and R_D values lower than 0.7Ω×mm.

The previous results were obtained without reducing the gate length from the starting value of 0.8 μm. After the T-gate formation process a 0.6 μm gate footprint length was obtained; and in this case the low noise and the power application devices gave a maximum current gain cut-off frequency (f_T^{max}) of 25GHz and 20GHz respectively. For the last one the gate drain breakdown voltage increased from 9 V up to 15 V. The negligible dependence of V_{PO} and I_{DSS} on the reduction of the gate length confirmed the high confinement efficiency of the carbon implanted layer.

In order to gain more insight into the behaviour of implanted carbon in GaAs, simulations were carried out by means of both a mono- and bidimensional bipolar drift-diffusion model, developed at Politecnico di Torino [3], for the low-noise 0.6 μm gate length SAGFET with the carbon buried layer. These simulations allowed for a comparison between the different carbon behaviour as shallow and deep level acceptor.

Figure 5 shows a good agreement between C-V measurements and the simulated charge profile in the active channel found assuming a carbon activation of 20% as shallow acceptor and 80% as deep acceptor; on the contrary neglecting the carbon deep level leads to a completely different profile as clearly reported in the same figure. The DC FET behaviour was also simulated and a comparison between numerical and experimental data is reported in Figure 6, even in this case the agreement is good if a carbon activation of 20% as shallow acceptor and 80% as deep acceptor is used for the simulations.

3. Conclusions

A new technology for the realization of self-aligned MESFET allowing for the realization of low-noise and power devices has been presented. A relevant role is played by the carbon different behaviour as shallow or deep acceptor level within GaAs. The proposed technology can improve both DC and RF performances by means of a proper carbon activation as evidenced by measurements. Simulation results confirmed the carbon implantation effectiveness in carrier confinement, due to its activation as deep acceptor within the FET substrate.

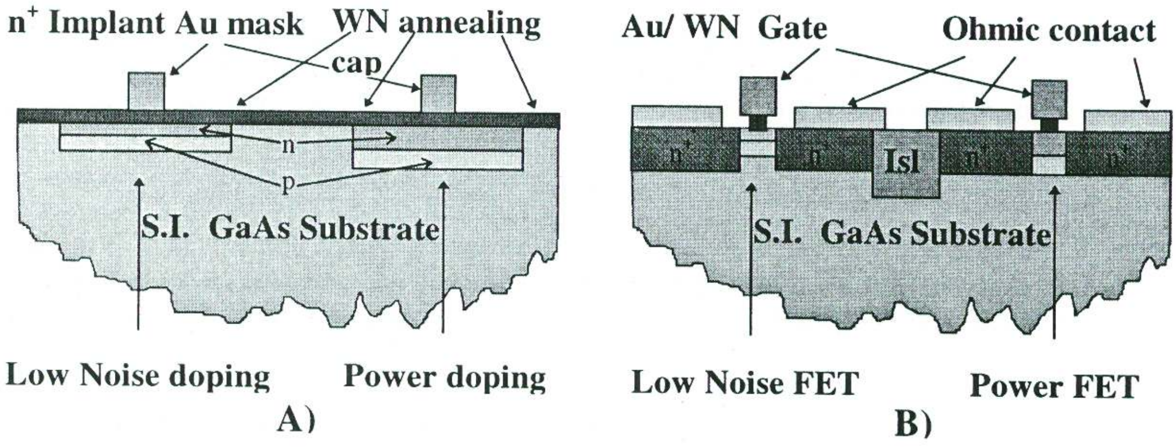

Figure 1) The two basic steps of the multifunctional SAGFET process technology:
A) Self-aligned n^+ doping formation; B) T-gate and ohmic contact formation.

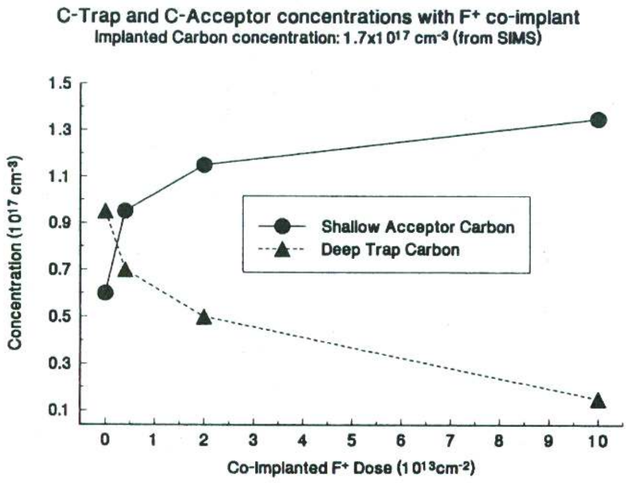

Figure 2) Variation of the electrical behaviour of carbon impurities after F^+ co-implantation: as F^+ dose increases the acceptors activation increases too while the deep-traps activation reduces; notice that the total sum of acceptor and deep-trap concentration is constant and equal to the implanted carbon.

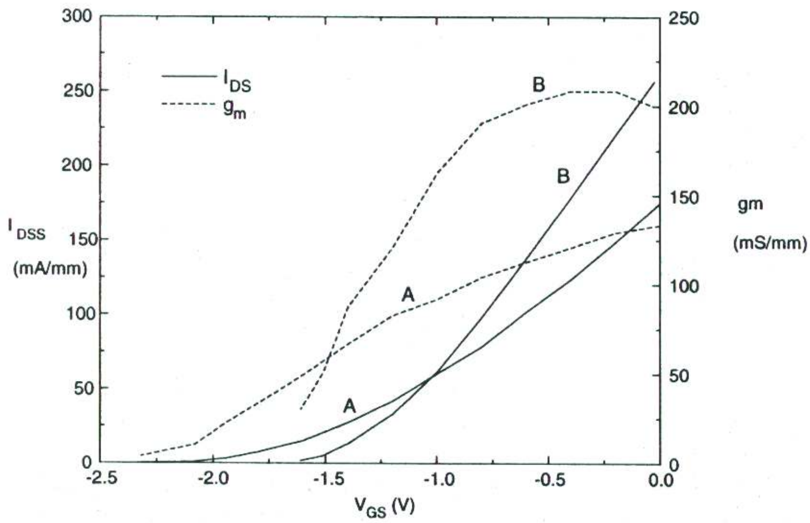

Figure 3) I_{DS} and g_m as a function of V_{GS} for low-noise SAGFET experimental devices, without (A) and with the buried carbon implanted layer (B).

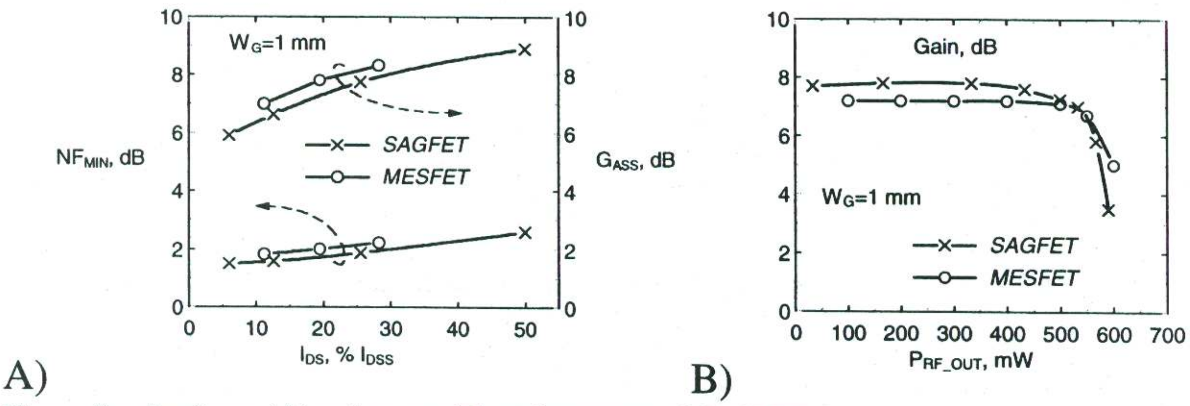

Figure 4) noise figure (A) and power (B) performances of SAGFET (crosses) compared to standard recessed- gate MESFET technology (circles).

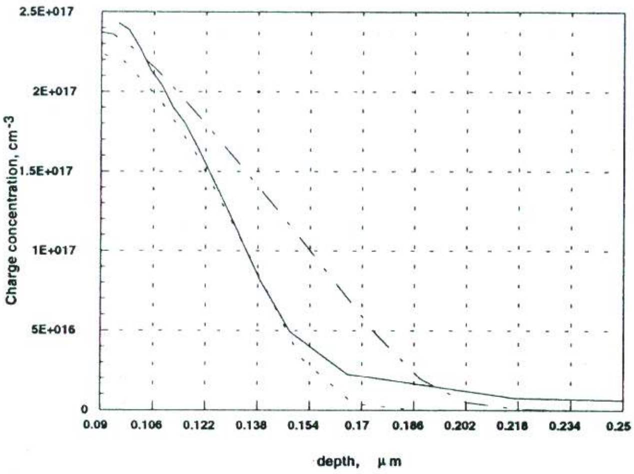

Figure 5) C-V profile in the active channel for measured (continuous line) and simulated 0.6 µm gate length SAGFET; simulations are relative to 2 different carbon activation behaviour: 20% activation of carbon as shallow acceptor and 80% as deep acceptor (dashed line), 20% activation of carbon as shallow acceptor and no deep level (dashed-dotted line).

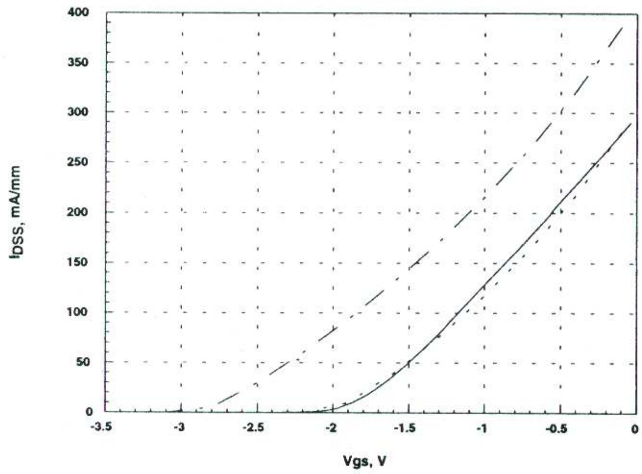

Figure 6) Transfer characteristics for measured (continuous line) and simulated 0.6 µm gate length SAGFET; simulations are relative to 2 different carbon activation behaviour: 20% activation of carbon as shallow acceptor and 80% as deep acceptor (dashed line), 20% activation of carbon as shallow acceptor and no deep level (dashed-dotted line).

References

1) F.Fumi, C.Lanzieri, D. Lupano, G.Negri, M.Peroni, A.Cetronio *"Multi-function Self-Aligned Gate (MSAG) Process for Low Cost, Increased Performance GaAs Integrated Circuits"*, Proc. of GAAS '96, 2B6, Paris 5-7 June 1996.

2) M. Peroni, P.D'Eustacchio, N. Di Virginio, R. Graffiti *"Electrical Behaviour of Carbon Impurities in Fluorine Coimplanted GaAs"*, J. Appl. Phys., Vol.80, NO.7, pp.3834-3839, 1 October 1996.

3) G. Ghione, M. Pirola, C.U. Naldi, *"Physical simulation of small-signal rate- dependent anomalies in GaAs MESFET's: a two-dimensional frequency-domain approach"*, Proceedings of IV SISDEP, pp.71-80, Zurich, Switzerland, 12-14 Sept. 1991.