

Influence of the Heterostructure Design on Noise Figure of AlGaIn/GaN HEMTs

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A small amount of characterization for noise at microwave frequencies has been done for AlGaIn/GaN HEMTs. Most of what has been published so far include a few papers trying to get best possible noise figures (such as [1]), studies comparing SiC and sapphire substrates [1,3], and one study of varying Aluminum mole fraction content in the AlGaIn barrier to see how it effects noise [2]. Little else has been published for trying to analyze the material structure or other ways to reduce the noise.

In this work, we will cover four topics. Three studies are presented on the effect of different epilayer structures on the noise figure of AlGaIn/GaN HEMTs in the 4-12 GHz frequency range. The material studies include varying Aluminum composition in the barrier, sapphire vs. SiC substrates, and, for the first time, influence of a thin AlN layer on the noise parameters, all three against frequency and drain current. In addition is a comparison of two equivalent circuit models at 5 GHz.

Unlike the findings in the earlier Aluminum composition study [2], Fig. 1 and 2 show that there is no variation in the noise parameters against frequency and current. We will show that that in order to have a fair comparison, the devices require similar f_t and f_{max} . The SiC substrate shows lower minimum noise figure at higher currents than the Sapphire substrates, while having similar noise against frequency when each is at its optimum bias. These measurements against bias support earlier studies but will show, for the first time by modeling, that the difference is indeed due to thermal heating. Measurements of devices with the thin AlN layer show a lower noise at higher current biasing than devices without the layer (see Fig. 3). The device with the AlN layer presents a better f_t and f_{max} for the same bias current as a device without the layer. We believed this causes the better noise performance, as seen in Fig. 4. Also presented, as seen in table I, is a six device comparison of the accuracy of the Pospieszalski and van der Ziel (Pucel) models with discussion of their strength and weaknesses.

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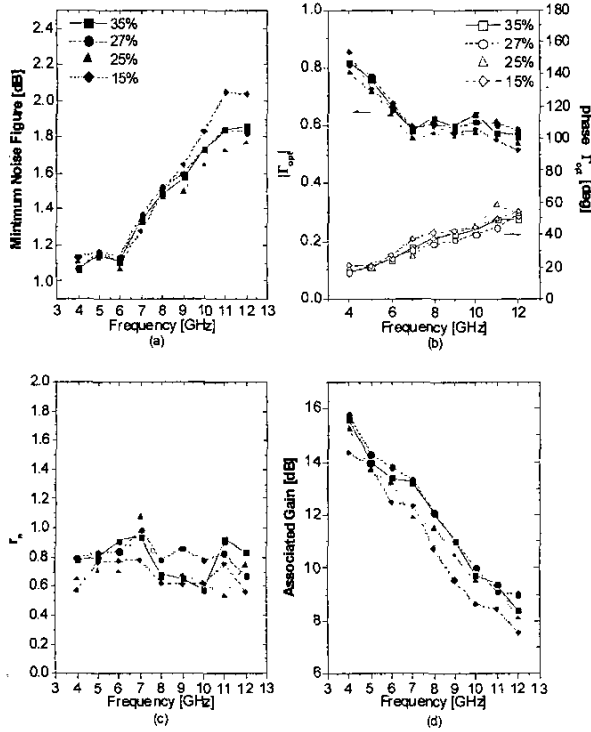


Fig. 1. Noise parameters of four devices from similar samples with varying Aluminum mole fraction, each biased for lowest noise (see Table I): (a) minimum noise figure. (b) optimum source impedance (magnitude and phase) (c) noise resistance (d) associated gain.

Measurements						
Al mole fraction	15%	25%	25% SiC	27%	35%	35% w/AlN
Nf_{min} [dB]	1.14	1.13	1.1	1.16	1.15	1.18
r_n	0.77	0.70	0.64	0.83	0.79	0.723
$ \Gamma_{opt} $	0.72	0.71	0.74	0.77	0.76	0.733
$\angle \Gamma_{opt}$ [deg.]	20.5	21.3	23.2	19.8	19.5	23.9
Associated Gain [dB]	14	13.7	14.6	14.3	14	12.7
$I_{ds} @ Nf_{min}$ [mA]	20	13	10	19	11	10
$V_{ds} @ Nf_{min}$ [V]	4	4	7	4	5	4
$f_t @ Nf_{min}$ [GHz]	19.7	19.4	21.4	23.3	22.3	21.3
$f_{max} @ Nf_{min}$ [GHz]	30.2	33.6	39	42.9	43.7	40.4
Pospieszalski Model						
Nf_{min} modeled [dB]	1.18	1.1	1.1	1.04	1.07	1.03
r_n modeled	0.74	0.59	0.72	0.81	0.83	0.721
$ \Gamma_{opt} $ modeled	0.70	0.66	0.71	0.74	0.74	0.72
$\angle \Gamma_{opt}$ modeled [deg.]	25.7	27.3	26.3	22.7	22.3	26.9
T_g [K]	607	292	250	358	462	988
T_d [K]	3445	3018	3893	3469	4454	3966
van der Ziel Model (using Sungjae Lee Formulation)						
Nf_{min} modeled [dB]	1.23	1.3	1.21	1.28	1.25	1.33
r_n modeled	1.21	0.98	0.83	1.04	0.97	0.95
$ \Gamma_{opt} $ modeled	0.80	0.75	0.77	0.79	0.78	0.766
$\angle \Gamma_{opt}$ modeled [deg.]	19.2	21.0	22.5	19.6	19.2	23.6
$\langle i_g ^2 \rangle$ [$10^{-24} A^2/Hz$]	7.05	12.0	3.55	7.09	7.23	6.74
$\langle i_d ^2 \rangle$ [$10^{-22} A^2/Hz$]	4.56	5.60	4.14	5.93	4.79	5.36
$ C $	0.80	0.79	0.82	0.80	0.75	0.739
$\angle C$	103	101	129	114	114	118

Table I. Measured noise parameters, values from Pospieszalski and van der Ziel models for all samples. All devices have a nominal gate length of 0.6 μm and gate width of 150 μm . All data is at a frequency of 5 GHz.

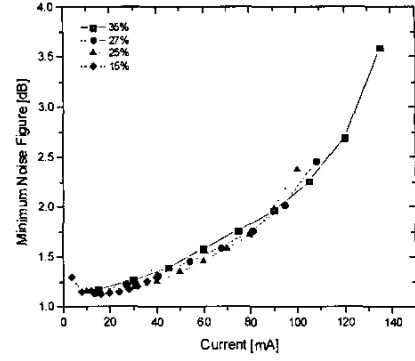


Fig. 2. Noise Figure versus I_{ds} of four devices with varying Aluminum mole fraction. Measurements made at 5 GHz with V_{ds} of each device as found in Table I.

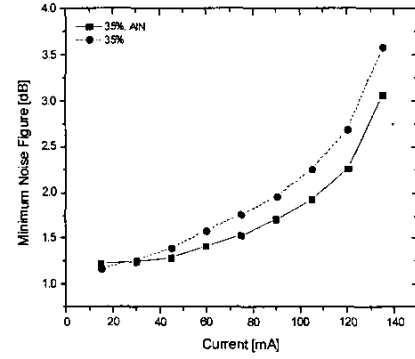


Fig. 3. Noise Figure versus I_{ds} of devices with and without an Aluminum-Nitride layer. Measurements made at 5 GHz with V_{ds} that gave the lowest noise measurements.

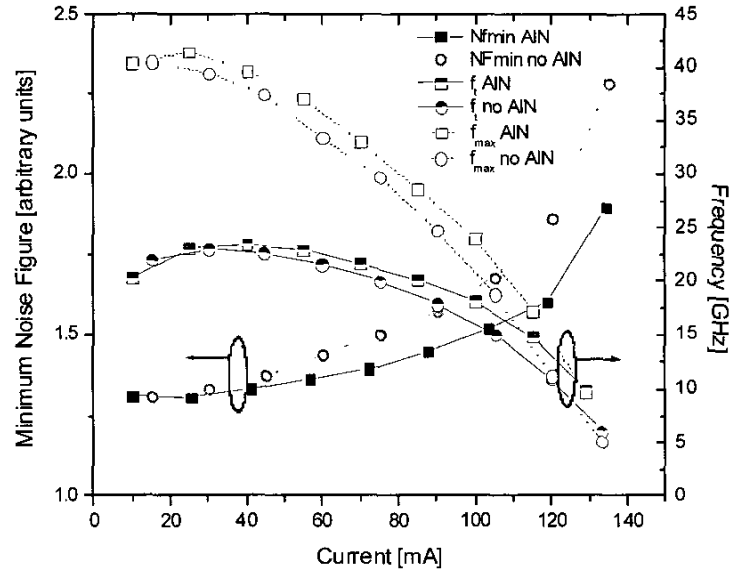


Fig. 4. Minimum Noise Figure, f_t , and f_{max} for similar devices with and without an AlN layer