Cryogenic Temperature Dependence and Modelling of RF-Noise Parameters of Carbon Doped InP/InGaAs HBT

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Abstract. The RF-Performance of InP/InGaAs HBT strongly depends on the ambient temperature. In this work we will present the rf-noise parameters (minimum noise figure F_{min}, equivalent noise resistance R_n and optimum generator reflection coefficient $\underline{\Gamma}_{opt}$) in dependence of bias condition and ambient device temperature in a range from $T_A = 300K$ down to cryogenic temperature of $T_A = 15K$. Additionally a consistent small-signal and rf-noise parameter equivalent will be presented.

RF-noise parameters of InP/InGaAs HBT

Using an on-wafer measurement set-up for cryogenic temperature measurements in combination with commercial s-parameter and rf-noise parameter measurement set-up [1] an rf-noise characterisation is performed in a frequency range from 2 GHz up to 18 GHz. Device under test are carbon doped InP/InGaAs non self-aligned HBT with an emitter area $A_E = 30µm^2$, grown by LP-MOVPE with non gaseous sources (TBAs/TBP, DitBuSi/CBr4, TMIn/TEGa) with nitrogen carrier gas. The carbon doped p-(InGa)As:C base ($p > 10^{19} cm^{-3}$) is compositionally graded to increase current gain (here: $B > 400$) and transit frequency (here: $f_T > 65$ GHz) and a high temperature in-situ annealing sequence is carried out in TMAs/N2 ambient at T > 600°C to activate the carbon doping in the base [Lit. Velling]. Fig. 1 shows the measured rf-noise parameters for four different ambient temperatures ($T_A = 300K$, 200K, 100K, and 15K) but identical collector currents I_C as well as collector-emitter voltage V_{CE}. With decreasing temperature the investigated device shows better rf-noise performance. This is demonstrated for the minimum noise figure F_{min} (fig. 1a) and equivalent noise resistance R_n (fig. 1b), which both decrease with decreasing temperature but constant collector current of $I_C = 10$ mA. The optimum generator reflection coefficient $\underline{\Gamma}_{opt}$ (fig. 1c) as well as the associated gain g_{ass} (fig. 1d) show only weak influence on temperature for identical bias condition.

The consistent small-signal and rf-noise model

Fig. 2 shows the "T"-like consistent small-signal and rf-noise model of HBT, based on temperature noise modelling of noisy impedances [3]. Consequently, equivalent noise temperatures are associated to all resistances. Using this model, both, s-parameters as well as noise-parameters can be modelled simultaneously and the different noise phenomena can be correlated directly with specific HBT regions. The noise due to the parasitic resistances is assumed to be thermal noise only, and therefore their equivalent noise temperature is equal to the ambient temperature T_A during measurement. All model parameters are found using evolutionary optimisation algorithm. A comparison of measured and modelled noise parameters is given in fig. 3, showing minimum noise figure F_{min} (fig. 3a) and equivalent noise resistance R_n (fig. 3b) in dependence on ambient measurement temperature T_A for constant collector current $I_C = 20$ mA. The excellent agreement between measured and modelled parameters can clearly be seen and demonstrates the capability of the consistent model. The bias and temperature dependence of the equivalent elements will be presented in more detail during presentation.

References

[1] H. Meschede et al., "On-Wafer Microwave Measurement Set-up for Investigation on HEMT's and High T_c Superconductors at Cryogenic Temperatures Down to 20 K", IEEE Transactions on Microwave Theory and Techniques, Vol. 40, No. 12, 1992

[2] P. Velling, et al. "A comparative study of GaAs- and InP-based HBT growth by means of LP-MOVPE using conventional and non gaseous sources", to be published in "Progress in Crystal Growth and Characterization of Materials", Dec. 2000.

[3] M. Agethen et al., "Small-Signal and RF-Noise Modelling of InP/InGaAs HBT", Proc. of "EDS HBT-Workshop & 12th III-V Semiconductor Device Simulation Workshop", Duisburg, Germany, October 2000

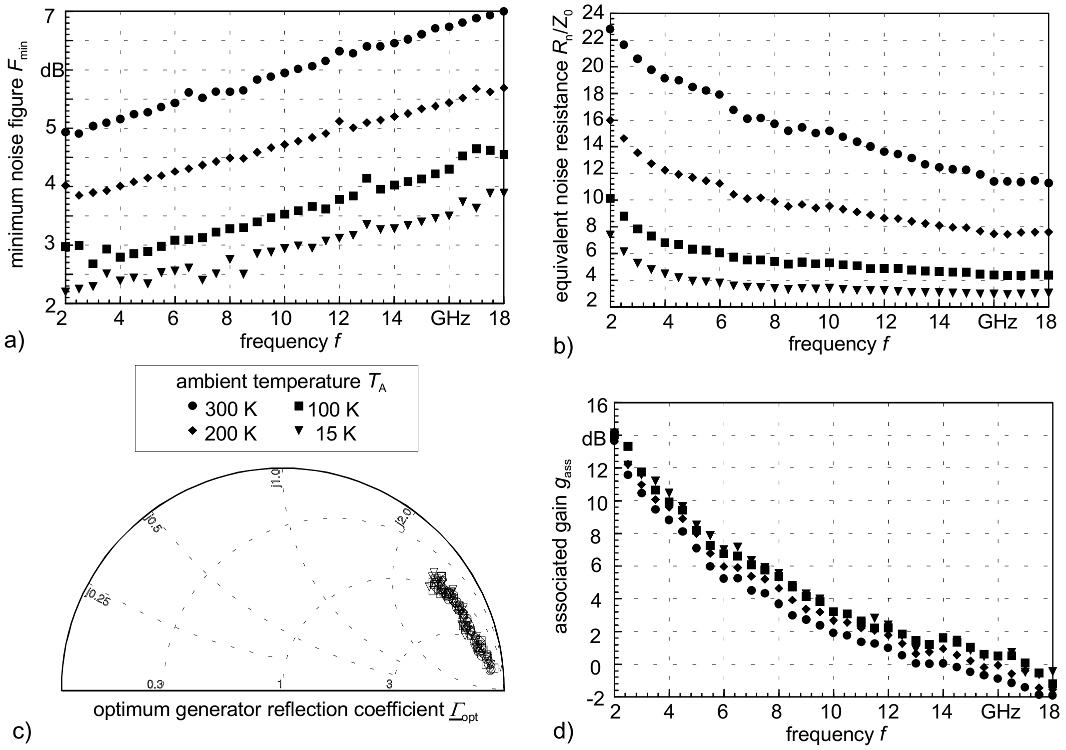

Fig. 1: RF-noise parameters of HBT in dependence on ambient temperature T_A.

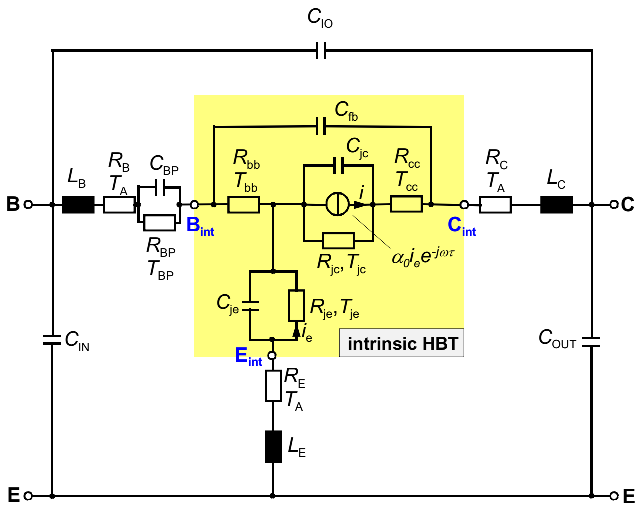

Fig. 2: The consistent small-signal and rf-noise equivalent circuit of HBT.

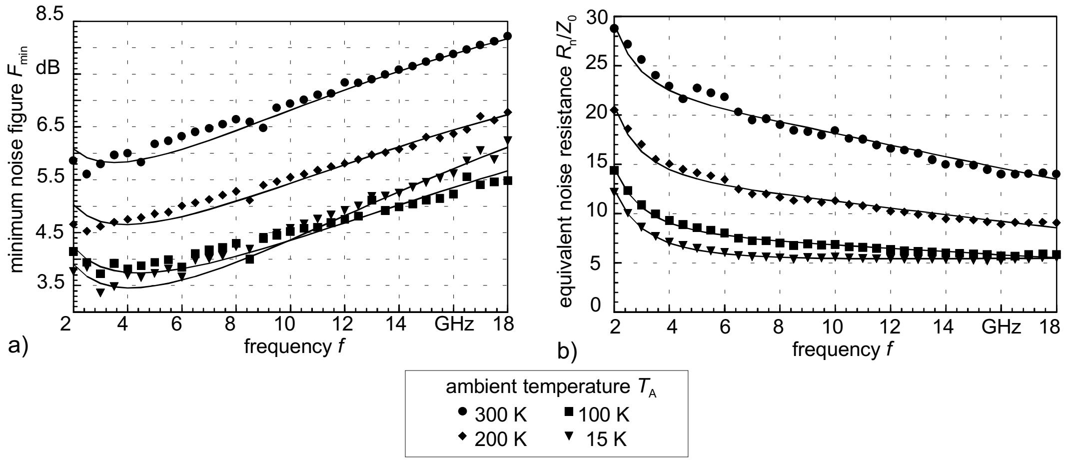

Fig.3: Measured and modelled rf-parameters of the investigated HBT (symbol (•): measured data; solid line (—): modelled data).