Low-Frequency Noise Characteristics of InGaAs/InAlAs Heterostructures

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Abstract. The low frequency noise of InGaAs/InAlAs heterostructures with various In concentration was measured in wide temperature range of 15K up to 450K and experimental characteristics compared with theoretical models of mobility fluctuations due to various scattering processes. Several p- and n-type doped lattice-matched $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ samples prepared by NTT reveal Hooge parameter $\alpha_H \cong 1$ and $\alpha_H \cong 2\times10^{-3}$, respectively, which is consistent with the 1/*f* energy partition fluctuations model. However, most of the n-type samples give α_H values of 4×10^{-6} to 3×10^{-5} or slightly higher in case of $In_{0.7}Ga_{0.3}As/In_{0.52}Al_{0.48}As$ pseudomorphic structures, which is closer to the quantum 1/*f* noise theory prediction of Hooge parameter about $\alpha_H \cong 10^{-6}$. Using the TLM structures noise analysis we determined, that contact noise was almost negligible.

Keywords: 1/f noise, InGaAs, HFET, MODFET, HEMT
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INTRODUCTION

The InGaAs/InAlAs heterostructure is the basic element of modulation doped field-effect transistors (MODFETs), in which the intrinsic InGaAs channel is sandwiched between two InAlAs layers with planar doping applied in the top layer. Due to the narrow band gap of InGaAs, the excess population of free electrons diffuses across the heterojunction and high carrier concentration in the channel is reached without doping it with impurities. This lack of impurity scattering allows for very high mobility of the two-dimensional electron gas in the channel, which is limited almost solely by the polar optical phonon scattering at the room temperature and then it is possible to study the intrinsic 1/f noise characteristics of a high purity material and their relation to the transport processes. In this paper we discuss two fundamental models of 1/f noise and compare theoretical predictions of Hooge parameter as a function of temperature dependent mobility.

According to the 1/f energy partition fluctuation model [1], mobility fluctuation is given by phonon scattering and the value of the Hooge parameter α_H is given as a ratio of lattice constant d and electron mean free λ. Since $\lambda = v\langle\tau\rangle$ and mobility $\mu = e\langle\tau\rangle/m^*$, where $\langle\tau\rangle$ is mean time between collisions, v electron velocity and m^* its effective mass, assuming the equipartition law of energy in 2-D case $E = kT = 1/2m^*v^2$ we get

theoretical dependence of the Hooge parameter on the mobility

$$\alpha_H = \frac{d}{\lambda} = \frac{d}{\mu\sqrt{2kTm^*}/e} \tag{1}$$

Another model of quantum 1/*f* noise considers fundamental 1/*f* fluctuation of the quantum mechanical cross sections and scattering rates, applicable to the interaction of a charged particle and its own field [2]. It represents the lowest limit of ubiquitous 1/*f* noise, inevitable in any system. The conventional, or incoherent quantum 1/*f* noise theory gives Hooge parameter as

$$\alpha_H = \frac{4a}{3\pi}\frac{(\Delta\bar{v})^2}{c^2} \tag{2}$$

where $a = e^2/\hbar^2 c$ is Sommerfeld's fine structure constant, c the speed of light in vacuum and $\Delta\bar{v}$ is the change in the velocity of the carriers in the interaction process considered, which is given by cross-correlation formulas derived in [3] and slightly modified in [4].

EXPERIMENTAL RESULTS

The relation between the intrinsic 1/*f* noise and mobility and scattering processes can be resolved from their temperature dependences, measured in both n-type and p-type $In_xGa_{1-x}As/In_{0.52}Al_{0.48}As$ quantum well heterostructures. We used samples with either lattice matched (x = 0.53) or pseudo-morphic (x = 0.7) channel. The schematic view of samples' structure is given in the Tab.1. All samples were grown on the semi-insulating InP substrate by MOCVD by NTT Advanced Technologies. The δ-doped MOCVD process is expected to induce less deep levels compared with MBE grown substrates. The ungated Hall elements were formed using In or unalloyed Ti/Pt/Au ohmic contacts and exposed cap layer removed by etching.

TABLE 1. Cross-sectional view of sample structure: lattice-matched n-type (A) and p-type (C), pseudomorphic n-type (B)

A	B	C	layer
n-$In_{0.53}Ga_{0.47}As$ 2×10^{19} cm^{-3} 20 nm	n-$In_{0.53}Ga_{0.47}As$ 2×10^{19} cm^{-3} 10 nm	p n-$In_{0.53}Ga_{0.47}As$ 2×10^{19} cm^{-3} 20 nm	cap
i-InP 6 nm	i-InP 5 nm	i-InP 6 nm	etch stop
i-$In_{0.52}Al_{0.48}As$ 10 nm	i-$In_{0.52}Al_{0.48}As$ 10 nm	i-$In_{0.52}Al_{0.48}As$ 10 nm	barrier
δ-doping $1\sim2\times10^{12}$ cm^{-2}	n-$In_{0.52}Al_{0.48}As$ 5×10^{11} cm^{-2} 7 nm	p-$In_{0.52}Al_{0.48}As$ 2×10^{18} cm^{-3} 20 nm	charge supply
i-$In_{0.52}Al_{0.48}As$ 10 nm	i-$In_{0.52}Al_{0.48}As$ 5 nm	i-$In_{0.52}Al_{0.48}As$ 30 nm	spacer
i-$In_{0.53}Ga_{0.47}As$ 15 nm	i-$In_{0.7}Ga_{0.3}As$ 10 nm	i-$In_{0.53}Ga_{0.47}As$ 15 nm	channel
i-$In_{0.52}Al_{0.48}As$ 200 nm	i-$In_{0.52}Al_{0.48}As$ 200 nm	i-$In_{0.52}Al_{0.48}As$ 200 nm	buffer
S.I. InP	S.I. InP	S.I. InP	substrate

Temperature dependence of the mobility μ and sheet carrier density n_S was determined by the Hall voltage measurement and results are plotted in Fig.1. Theoretical analysis indicates, that mobility at 300K is limited by polar optical phonon scattering to about 11000 cm^2/Vs, whereas at low temperatures below 50K mobility is restrained by alloy scattering to about 70000 cm^2/Vs for lattice-matched $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$. Much lower mobility value of about 25000 cm^2/Vs at $T = 10K$ in pseudomorphic samples is probably caused by interface scattering due to the smaller thickness of channel and spacer layers.

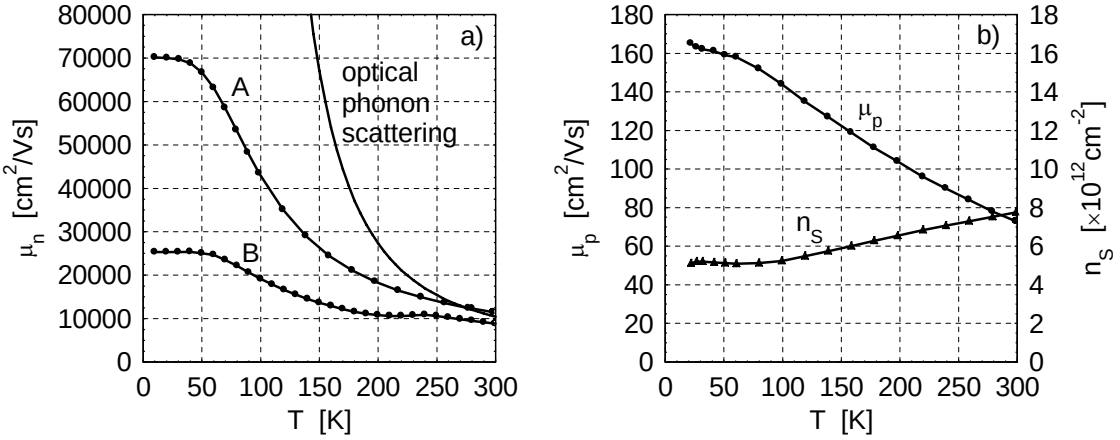

FIGURE 1. a) Temperature dependence of mobility in n-type samples and theoretical limit given by optical phonon scattering (A denotes $In_{0.53}Ga_{0.47}As$ and B $In_{0.7}Ga_{0.3}As$ channels)
b) Temperature dependence of mobility and sheet carrier density in p-type sample

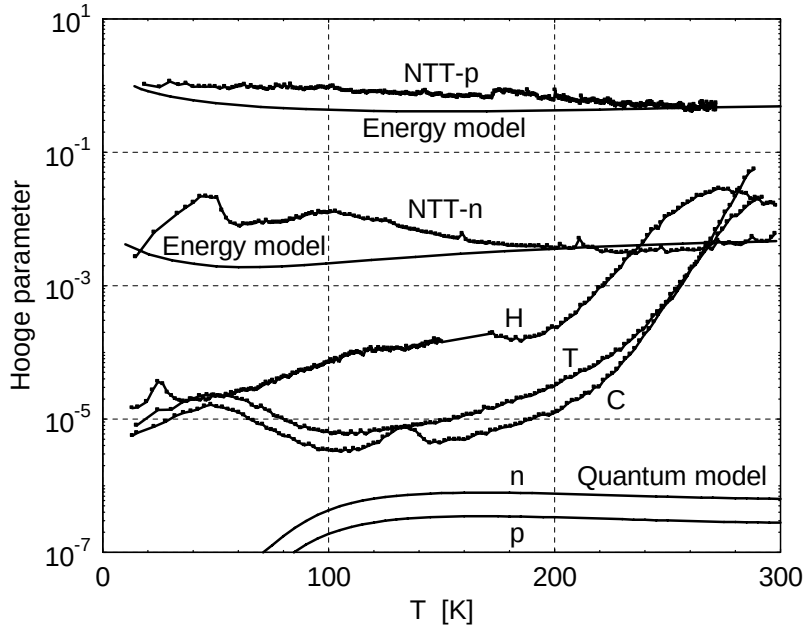

FIGURE 2. Temperature dependence of p- and n-InGaAs/InAlAs Hooge parameter, measured on various samples (NTT greek cross, lattice-matched T, C and pseudomorphic H). Lines stand for 1/f energy partition fluctuation and quantum 1/f noise theories simulation

Temperature dependence of the voltage noise spectral density was measured using NF Instruments preamplifier with battery power source, Advantest R9211A FFT analyser and Iwatani helium cryostat and Hooge parameter determined. Results are plotted in Fig. 2 together with theoretical $\alpha_H(T)$ dependence, evaluated according to Eq.1 and Eq.2 for both $1/f$ noise models. The $1/f$ energy fluctuation model considering phonon scattering is in a good agreement with experimental results for both p-type and n-type samples, provided by NTT as a greek cross Hall elements with indium contacts. However, much lower values of Hooge parameter were measured on Hall bar samples prepared in our laboratory using NTT wafers with identical mobility. For lattice-matched samples α_H was in the range of 4×10^{-6} to 3×10^{-5} for temperature below 200K, where noise spectral density was $1/f$ like. These values are close to quantum $1/f$ noise theory prediction of α_H slightly lower than 10^{-6}. Similar results we obtained on samples provided by Communication Research Laboratory [5]. For pseudomorphic samples Hooge parameter was about one order higher. There was almost no difference between Indium or Ti/Pt/Au contacts. The influence of contact noise was found negligible by measurement of TLM structures of 5, 10, 25, 40 and 80μm width in comparison with 1000 μm Hall bar samples. For temperature higher than 250K generation-recombination noise with $1/f^2$ spectra became dominant and from the Arrhenius plot of Lorentzian spectra time constant up to temperature 440K the value of activation energy of traps was determined $\Delta E = 0.63$eV.

CONCLUSION

Temperature dependence of Hooge parameter was measured on InGaAs/InAlAs samples with various In concentration and mobility and compared to theoretical models of intrinsic $1/f$ noise. For p-type samples experimental results were consistent with $1/f$ energy partition fluctuation model, whereas much lower values of $\alpha_H \cong 10^{-5}$ measured on n-type samples seem to approach quantum $1/f$ noise theory limit.

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