LOW TEMPERATURE PROPERTIES OF GaAs MESFET

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Abstract - **The industrially manufactured low-noise GaAs FET noise and gain parameters were experimentally investigated in the temperature range of 80-300 K at frequency 12 GHz. The process of cooling down to the 80 K permits to reduce the minimum noise figure of the studied samples to ~ 1 dB; simultaneously the associated gain increases up to ~ 2 - 2.5 dB. The comparative analysis of minimum noise figure changing in temperature range in accordance to the semiconductor physical parameters was carried out. It was established that the noise figure minimum under the cooling depends essentially on the carrier concentration of epitaxial structure.**

I. INTRODUCTION

The objective was to determine the actual values of principal electrical parameters of GaAs microwave transistors while cooling to cryogenic temperatures. These data need to estimate the possibilities of realization of active generators (based on GaAs MESFET) in hybrid microcircuit with high-temperature superconductor.

II. EXPERIMENTAL SAMPLES

Static and dynamic parameters of the GaAs FET (gate physical length $lg \approx 0.4$ µm, channel width $w = 190$ µm) were studied experimentally. The FET samples were made on the full-scale produced n^{+}-n-n_b-i-GaAs epitaxial structures grown using the MOS-hydride epitaxy. Transistors were made by the standard self-aligned technology with deepened gate using electron-beam litography with the following Ti, Ti_xN_{1-x} and Au deposition. The total thickness was about 0,6 µm so as exclude the creeping of metal under the mask during evaporation and gold diffusion into channel region.

Three groups of transistors differed by charge carrier concentration in active layer were taken for studies. The carrier concentration in transistor groups I, II and III were respectively: 2.2×10^{17}, 3.5×10^{17} and 5×10^{17} cm^{-3}.

The transistor design of experimental samples was essentially simplified in comparison with similar serial devices. The gate contact area was increased by 4 times. Under the cooling down to 80 K, a reliable contact was provided for the probes. That is why the noise figure increases on 0.2-0.3 dB as well as the power gain decreases of 1.5-2.0 dB in the experimental samples in comparison to serial transistors, but this provided the reproducibility of experimental results.

Static characteristics of the transistors were measured at dc, while the gain and dynamic parameters were measured at frequency 12 GHz accordingly to technique described by Bosiy et al [1].

III. EXHERIMENTAL RESULTS

I-V characteristic studies

Experimentally obtained *I-V* characteristics (at the temperature interval 80 - 300 K) for transistors of different designs are given in Fig. 1 and Table 1.

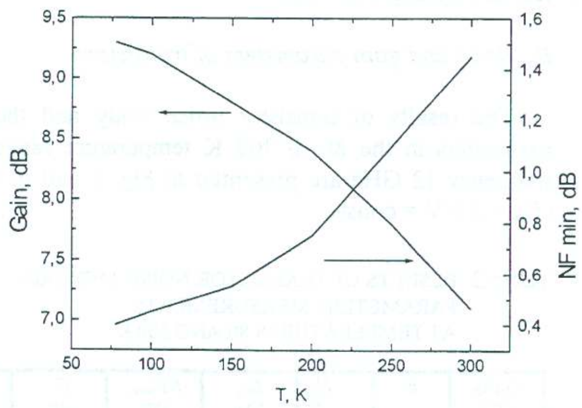

Fig. 1. Noise factor and gain of I group transistors via temperature at the frequency 12 GHz

It is known that charge carrier mobility and drift velocity of the active layer should grow when transistor is cooling down to the cryogenic temperature range [2]. Our experiment shows that while cooling GaAs FET down to the 80 K both drain current and slope S of *I-V* curve increase in 30-50%, while the output conductance G_{out} increases by factor of 2 - 5. A degree of transistor parameter changing under cooling process depends on the physical parameters of the starting semiconductor structure.

The measurement of *I-V* curve slope S shows the additional evidence concerning the charge carrier concentrations in the channel. To illustrate this, use the group III transistors ($n \approx 5\times10^{17}$ cm^{-3}) where S values are

Table 1. MAJOR PARAMETERS OF VARIOUS GROUPS OF TRANSISTORS AT 80 K AND 300 K

GaAs FET group	#	I_{dss}, mA at U_{ds}=2. 5 V, U_{gs}=0	S, mA/V at U_{ds}=2.5 V, U_{gs}<0.2 V	G_{out}, ,mS at U_{ds}=2. 5 V, U_{gs}=0	T_a, K
I	1	17.0 22.0	22 37	0.6 2.0	300 80
	2	13.5 18.5	28 37	0.9 1.8	300 80
II	3	17.0 23.8	33 44	1.2 3.2	300 80
	4	34.5 46.8	35 41	1.2 2.4	300 80
III	5	14.2 21.0	33 53	0.8 4.0	300 80
	6	12.3 17.6	35 57	1.0 4.0	300 80

approximately 1.5 times more than those for transistors of the group I (with $n \approx 2.2\times10^{17}$cm $^{-3}$). This is true as at room temperature so at 80 K. It should be noted that in the temperature range used the transistors studied do not all demonstrated the normal operating current-voltage mode at some conditions. It is may be caused by defects of epitaxial GaAs structure in the channel or by transistor technology imperfections.

B. Noise and gain parameters of transistors

The results of transistor noise study and their gain parameters in the 80 to 300 K temperature range at the frequency 12 GHz are presented in Fig. 1 and in Table 2 (U_{ds}= 2.5 V = const).

Table 2. RESULTS OF TRANSISTOR NOISE AND GAIN PARAMETERS MEASUREMENTS AT TEMPERATURES 80 AND 300 K

GaAs FET group	#	U_{gs}, V	I_{ds}, MA	NF_{min}, DB	G, dB	T_a, K
I	1	0,35	8.0 9.8	1.37 0.41	7.4 9.2	300 80
	2	0.26	6.8 9.1	1.4 0.35	7.5 9.6	300 80
II	3	0.33	6.1 9.8	1.40 0.37	7.8 10.3	300 80
	4	0.86	6.3 9.2	1.50 0.37	7.8 9.5	300 80
III	5	0.26	6.0 7.8	1.46 0.33	8.2 10.25	300 80
	6	0.20	6.1 8.2	1.50 0.30	8.3 10.3	300 80

Noise characteristic of transistor is determined by the physical length of gate, material quality, and parasitic resistance of drain and by gate metallization [2]. In the GaAs-based FET, a thermal noise dominates, so the cooling of transistor is the most efficient way to decrease noise. That is why, the noise factor was reduced by 1 - 1.2 dB (because samples were studied at the ambient temperature T_a = 80 K and frequency 12 GHz). Correspondingly, the power gain was increased by 2 dB due to the growth of charge carriers drift velocity and their mobility in the channel.

Evidently, there should be no correlation between the minimum noise factor values measured at room temperature and after cooling. This may be attributable to the different contributions from thermal noise of parasitic resistance to the NF_{min} value. The transistors of group III (made with the structure with elevated charge carrier concentration in the channel) demonstrates better noise factor values after cooling. One of the reason of this fact might be a discrepancy in the electrical characteristics of the semiconductor buffer layer - active layer interface. It is well known that the interface quality is of vital importance when seeking to obtain the minimum noise factor value [2]. The results of our_investigations demonstrate that major parameters (NF_{min} ,G, etc.) spread for the transistors of the same design but taken from different batches exceeds that for the transistors taken from the same batch.

In the serial transistors, the noise parameters are substantially improved due to concurrent reducing the gate physical length down to 0.25 - 0.3 μm and by reducing of gate metallization resistance (the later reducing is achieved in the multi–section gate).

C. Self-excited oscillators on GaAs MESFET

The results of output measurements of different transistors (with the fixed oscillation frequency of 12 GHz) in the 80 to 300 K temperature range (U_{ds} = 6 V = *const*) are presented in the Table3.

Table 3. PERFORMANCE OF SELF-EXCITED OSCILLATOR WITH FREQUENCY OF OSCILLATION 12 GHZ AT TEMPERATURES 80 AND 300 K

GaAs FET group	#	I_{ds}, MA	P_{out}, MW	η, %	T_a, K	Note
I	1	16.5 28	11.8 24.4	11.9 14.5	300 80	
	2	17.0 28	13.6 28.8	13.3 17.1	300 80	
II	3	23 37.8	23.4 33.6	16.9 14.8	300 80	U_{ds} = 6 V
	4	22.5 43	25.5 31.4	18.9 12.2	300 80	
III	5	22.3 38	21.3 40	15.9 17.5	300 80	

To obtain transistor parameters in the oscillating mode, we used a common-source circuit of the self-excited oscillator. A dielectric resonator (connected to the 50Ω microstrip line based on alumina substrate) was used in the gate frequency-controlling circuit. The feedback was provided by a capacitance in the source circuit. The automatic gate bias was applied from resistor into the source circuit. The gate circuit had a matched load (a stabilizing resistor) for both the spurious oscillation suppression, and the operating mode stabilization. The isolation of output circuit and self-excited oscillator from the load was provided by use of resistive attenuator (6 dB).

The obtained for the group I and III transistors results show that at cooling down to 80 K their output grows about twice, without an additional impedance trimming. A slight output power increase for the group II transistors seems a result from substantial change in the transistor equivalent circuit parameters upon cooling down to the cryogenic temperatures. This conclusion was supported by the fact of the efficiency drop for the group II transistors upon cooling (contrary to this, for the transistors of groups I and III, the efficiency grew upon cooling down to the cryogenic temperatures). It should be noted that the transistor output power was determined taking into account the dissipation losses of resistive attenuator.

To study the GaAs-based chip FET's in a wide temperature range we have developed and constructed a special measuring set (with all the necessary accessories) based on the standard units for noise factor measure. The peculiar contact equipment has been developed to connect the FET studied to the regular microwave transmission-line system, to set the proper dc supply mode and to provide the steady operating mode [1].

A distinguishing feature of the developed contact equipment (used to investigate the chip transistor parameters in the temperature interval 80 to 300 K) is a local cooling of the sample studied by nitrogen vapor-gas low supplied immediately to the sample. Such a local cooling has a number of advantages over cooling the whole contact equipment. Heat insulation reduces both the transistor input and output dissipation losses; besides, there is no condensed moisture at the inner coaxial surfaces and this substantially reduces the microwave parameters measuring errors.

To prevent the case of contact equipment from cooling below 273 K, a special heating element was introduced to the measuring set design. To change the transistor cooling degree, one should change the nitrogen vapor-gas flow supplied to the sample. Monitoring of ambient temperature was performed by the measurement of thermo-electromotive force from the pre-calibrated copper-constantan thermocouple. This thermocouple was made as a stage on which the transistor studied is immediately placed.

IV. CONCLUSIONS

The results of transistors parameters study in the temperature range of 80 - 300 K confirm the possibility of oscillator realization as a source of EM irradiation at the frequency of 12 GHz need for Josephson contacts testing at cryogenic temperature. The performances of GaAs MESFET auto-oscillator permit to use it together with the devices based on high temperature superconductors.

V. REFERENCES

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