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INVESTIGATIONS OF THE NOISE PERFORMANCES OF THE FET АП354Г AT LOW TEMPERATURE

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Noise performances of the GaAs MES FET АП354Г are investigated at the low temperature. The noise voltage of the transistors is 0.25÷0.4 $nV/Hz^{1/2}$ at the optimal drain current 30÷100 mA at the temperature of liquid helium. The optimal value of the signal source impedance is 20÷100 kΩ. It was exposed that the transistor without package had advantage compared with the packaged transitors due to a better condition for cooling at the liquid nitrogen.

The investigation has been performed at the Laboratory of Particle Physics, JINR.

Исследование шумовых характеристик транзисторов АП354Г при низких температурах

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Исследованы шумовые характеристики полевых арсенид галлиевых транзисторов АП354Г при низких температурах. При работе в жидком гелии эквивалентная э.д.с. шума транзисторов составила 0,25÷0,4 $нВ/Гц^{1/2}$ при оптимальном токе стока 30÷100 мА. Оптимальное значение сопротивления источника сигнала для исследованных транзисторов — 20÷100 кОм. Выяснено, что вследствие лучших условий охлаждения при работе в жидком азоте бескорпусные транзисторы имеют более хорошие шумовые характеристики, чем корпусные.

Работа выполнена в Лаборатории сверхвысоких энергий ОИЯИ.

Introduction

The cooled amplifiers often are used in Low Temperature Physics. Their usage does not only decrease intrinsic noises but improves all the measurement system performances due to the sensors and amplifier to be located closer to each other. In this case the influence of the ambient noises decreases because the length of small signal wires diminishes. In the case of resonance circuits of sensor sampling the quality factor of selective schemes increases and their performances increase too.

Traditional GaAs transistors are used as active elements of the cooled amplifiers at the temperature range lower than 77 K. In this material the energy of the dopant activation is very low and carriers do not freeze out at the temperature of liquid helium.

In this paper the investigation of the noise performances of the GaAs MESFET АП354Г (NPO «Saturn», Ukraine) with and without package is described.

Method

The simplest scheme for the input circuit noise of the amplifier is shown in Figure 1. Here C_{in} is the input capacitance mainly determined with the gate-source capacitance C_{gs}, e_n and i_n are equivalent sources of the noise voltage and current.

It is known that for the field-effect transistors the sources of the noise voltage are the thermal noise of the channel resistance $V_{n_{ch}}$ and low frequency fluctuations caused by the fluctuations of the velocity of the charge carrier recombination in the nonsaturated region $V^2_{n_f}(\omega)$:

$$e_n^2 = V^2_{n_{ch}} + V^2_{n_f}(\omega). \qquad (1)$$

The first part of the equation can be expressed with the effective temperature of the channel, T_{ch}, and its transconductance, g_m, the second one depends on technological factors and is hard to be calculated:

$$e_n^2 = \frac{8}{3}\,\frac{k_B T_{ch}}{g_m} + V^2_{n_f}(\omega). \qquad (2)$$

The current noise also consists of two parts. The first one, $I_{n_{ch}}$, is caused by the noise voltage fluctuations along the channel which induce the noise charge in the gate since the gate is capacitively coupled to the channel through C_{gs}; the second is the shot noise of the gate leakage current I_{n_g};

$$i_n^2 = I^2_{n_{ch}} + I^2_{n_g}. \qquad (3)$$

These parts can be expressed with transconductance g_m, the effective temperature of the corresponding part of channel T^*_{ch}, the gate-source capacitance C_{gs} and the gate leakage current I_g:

$$i_n^2 = \frac{16}{15}\,\frac{k_B T^*_{ch} C_{ga}}{g_m} + 2eI_g. \qquad (4)$$

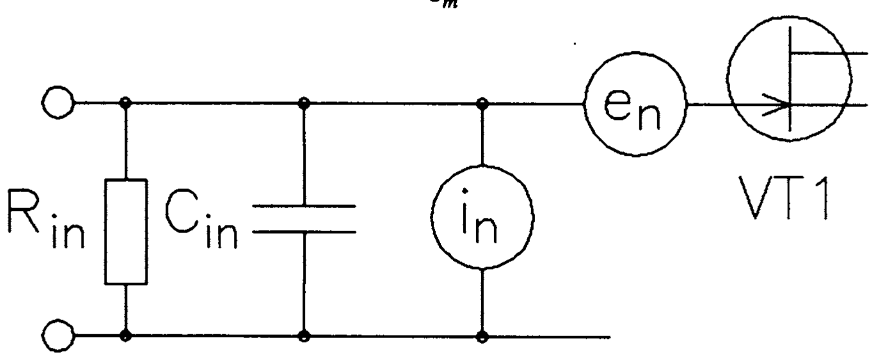

Fig.1. The equivalent diagram of the input circuit of the FET amplifier

Experiment and Discussion

We have investigated the temperature curves of the transconductance, input impedance and noise of the 20 transistors. The temperature curves of the transconductance g_m at different drain current are shown in Figure 2. As usual for the field effect transistors the temperature diagrams $g_m(T)$ repeat the temperature diagrams of the carrier mobility $\mu(T)$ [2]:

$$g_m = \frac{\rho_t L_w n_1^{1/2} q}{L_l} \mu T, \tag{5}$$

where ρ_t is the technological factor; L_w, width of the channel; n_1, dopant density; q, charge of electron; L_l, length of the channel. Two parts of the diagram can be seen. In the temperature range higher than 50 K the mobility is determined mainly with the scattering on phonons and proportional to $T^{3/2}$. At the lower temperature the mobility usually decreases because of the scattering on the impurity centers. But for high doping materials the influence of the impurity centers decreases due to the shielding effect of the carriers. In the result, the plateaus on the temperature diagram are obtained when the temperature is lower than 50 K.

The gate leakage current decreases with the ambient temperature and is not measurable in the temperature range lower 100 K (Figure 3).

Following the approach from [1] the contribution of each noise source is determined. We have neglected the noise due to the load resistance. The typical results are shown in Figures 4 and 5. The first part of the equation (1,3) is independent of the frequency, the second one is in inverse proportion to the frequency. It is seen from Figure 4 that the low frequency fluctuation $V_{n_f}^2(\omega)$ is negligibly small at the low temperature and this frequency region. The other part is lower by several times.

The second part of dependence $i_n(t)$ is independent of the frequency, the first is in direct proportional to the frequency. It is seen from Figure 5 that shot noise of the gate leakage current I_{n_g} is invisible at low temperature.

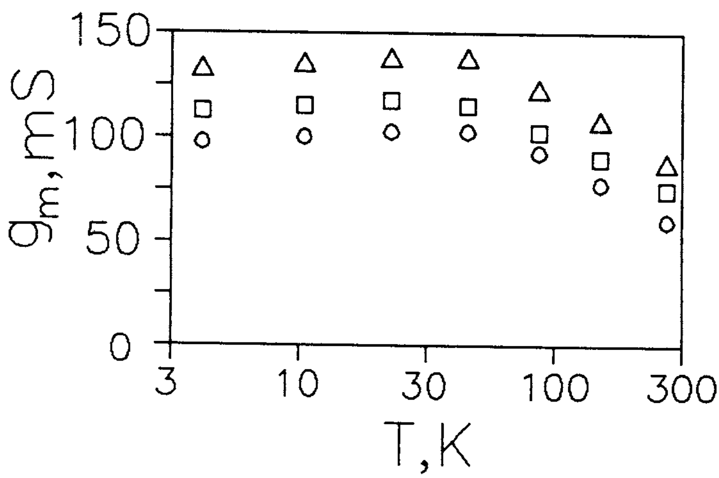

Fig.2. The temperature curves of the transconductance of the transistor АП354Г. The drain current is: ○ — 8 mA, □ — 15 mA, △ — 35 mA

The optimal value of the signal source impedance R_{opt} is:

$$R_{opt} = \frac{e_n}{i_n}. \tag{6}$$

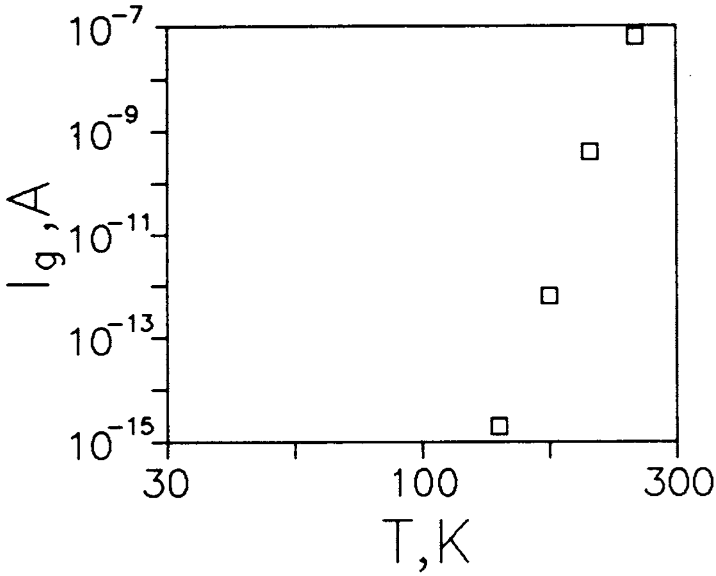

Fig.3. The temperature curve of the gate leakage current I_g of the transitor АП354Г

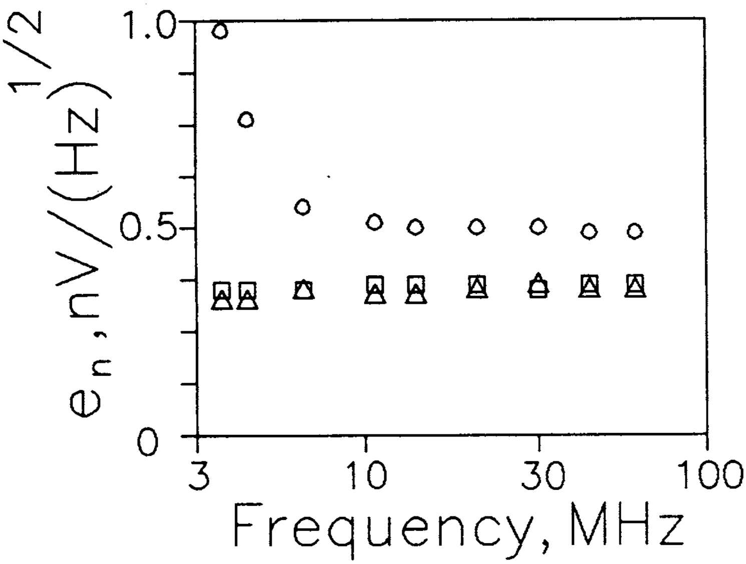

Fig.4. The frequency curves of the voltage at different temperatures. o — 300 K, □ — 77 K, △ — 4.2 K

The combined effect of the noise sources is minimized for this value of the signal source impedance. R_{opt} is 30÷100 kΩ for АП354Г at this frequency range.

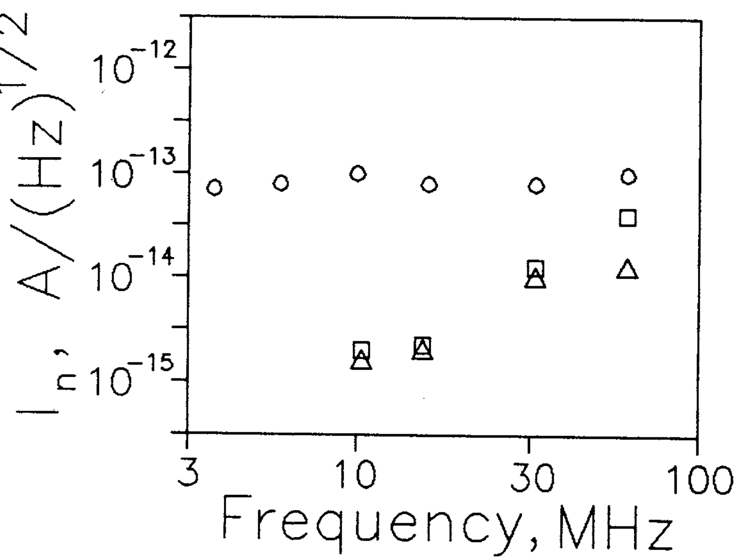

Fig.5. The frequency curves of the noise current i_n at different temperatures. o — 300 K, □ — 77 K, △— 4.2 K

Using the equations (3,4), we have calculated the ambient temperature curves of the effective temperatures T_{ch} and T^*_{ch}. It was assumed that T_{ch} and T^*_{ch} could be decreases using the transistors without a package. In this case we have a possibility to create a better condition for cooling at the liquid nitrogen and helium. For this purpose we have measured transistors with a hole in the package. The results of the measurements of the noise voltage with and without a hole are shown in tabular. The transistors without a package have shown the same results.

Temperature	293 K		77K		4.2 K	
Transistor	T_{ch}, K	T^*_{ch}, K	T_{ch}, K	T^*_{ch}, K	T_{ch}, K	T^*_{ch}, K
With package	300 ± 30	—	85 ± 10	85 ± 30	75 ± 10	80 ± 30
Without package	300 ± 30	—	75 ± 8	85 ± 30	72 ± 8	80 ± 30

The transistors with and without a package were cooled many times with a cooling speed of 5 K/s. They did not show any degradation of their characteristics.

The amplifier (Figure 6) utilized a cooled transistor АП354Г as the input device was constructed [3]. The input niose of the amplifier is 0.5 nV/ $Hz^{1/2}$ at 4.2÷100 K. The power dissipation is 25 mW. The amplifier is used in a HTS SQUID magnetometer. The additional noise of the magnetometer due to amplifier is $5\cdot10^{-6}$ $\Phi_0/Hz^{1/2}$ at the transfer function $\partial V/\partial\Phi \cong 100$ µV/ Φ_0. It is lower than the noise of usual HTS SQUIDs by several times.

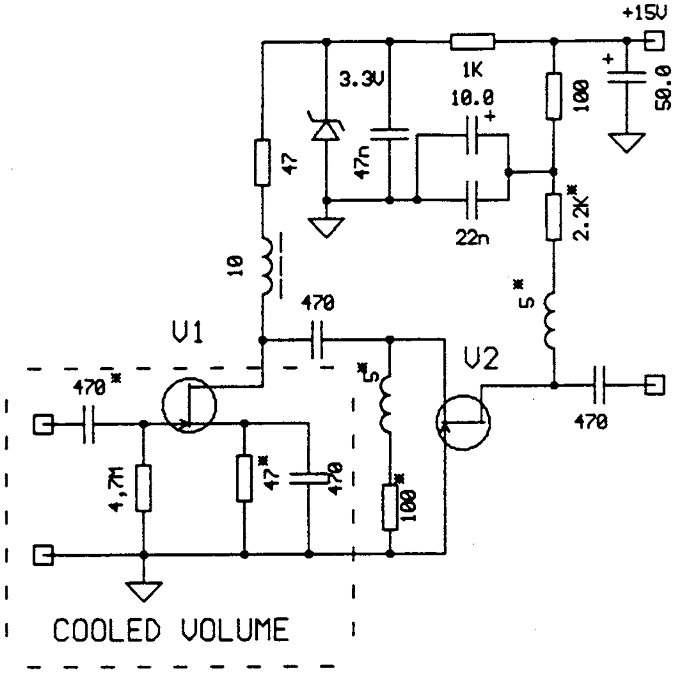

Fig.6. The diagram of the cooled preamplifier

Conclusions

1. The operation of the gallium arsenide field-effect transistors АП354Г was investigated at low temperature. The temperature curves of amplification and noise were estimated.

2. It was exposed that the transistors without a package are preferable than the transistors with a package because of better conditions for cooling in the liquid.

3. The investigations allowed to create the amplifier with noise lower than the usual HTS RF SQUID noise.

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