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F. Celani, U. Gambardella, A. Giorgi, A. Saggese, S. Catà
INFN - Laboratori Nazionali di Frascati, P.O.Box 13, 00044 Frascati (Italy)

S. Pace
Dipartimento Fisica Università di Salerno, 84100 Salerno (Italy)

ABSTRACT

In the framework of using Superconducting Tunnel Junctions as high resolution ionizing particle detectors, the use of cryogenic preamplifiers is opportune: we have studied the noise and gain-bandwidth characteristics (10 kHz–50 MHz) of some RF Si JFETs (2N4416A, U311), a Si MOSFET (BF982), and GaAs MESFETs (CF100, CF300) at 300, 77 and 4.2 K. Some theoretical features of such devices at cryogenic temperatures are reported and compared with experimental results. To obtain quantitative values of transconductance, mainly at cryogenics temperatures, we developed a curve tracer based on a rearrangement of two True Instrumentation Amplifiers because commercial ones were useful only for qualitative analysis. In noise measurements, as a front-end preamplifier we used, at all temperatures, a 20 db voltage amplifier, home-made, based on three selected U311s kept at 77 K for low noise operation. According to our measurements the "best" devices, for our purposes, is the U311 at 300 and 77 K and the only one that works satisfactorily at all temperatures, after selection for 4.2 K operation, is the CF300. Our measurements are, roughly, in accord with theory except for the BF982 that isn't, practically, operating at 4.2 K.

INTRODUCTION

Since 1969 (1) some efforts have been made to study the possibility of using Superconducting Tunnel Junctions (STJ) as very high resolution nuclear detectors. The good theoretical performance of such detectors lies in the intrinsic low value of the energy (ε) necessary to break the Cooper pairs in the superconducting films arranged in a configuration Superconductor-Insulator-Superconductor (SIS). Such energy is of the order of 1 meV for "conventional" superconductors, i.e. about one thousand times lower than the best presently allowable semiconductor detector (Ge). Moreover, the energetic resolution (w) of almost any kind of detector is just proportional to the square root of ε, thus it should be possible to obtain an improvement on the energetic resolution of about 30–50 times.

Unfortunately, up to now (2) it has been impossible to get such good results: the "real" value of ε was not too far from that expected (just 3 times higher than the theoretical value), but a "bad" value of w, i.e. about 10–30 times higher than calculated, has been found. In our opinion, following a theoretical study of the intrinsic noise of STJs (3, 4), such a large difference can arise, to a large extent, from the inadequate collection process and from the arrangement of the front-end electronics.

In almost all the performed experiments, the detector is in thermal contact with a liquid He^4, or sometime a liquid He^3, bath, while the preamplifier is located at room temperature, linked to the detector by long coaxial cables, with some impedance mismatching points. Just in one experiment (2) was the preamplifier located near the detector (about 40 cm away) at liquid nitrogen temperature, but the bandwidth of the electronics used was rather low (-3 db at 1 MHz). To be sure, in such an experiment according to some theoretical calculation on the signal dynamics of the STJ, the reported bandwidth was large enough to completely collect the signal, but the experiment showed "inadequate" overall energetic resolution. Because of this, and of our analysis of the configuration STJ-front end electronics (3,4), we have studied several conventional (non superconductive) active devices that can work satisfactorly mainly in a liquid nitrogen bath with some tests performed down to liquid helium temperature. Because of environmental constrains and of the type of signal, we have limited our investigations to devices that can provide the following performance:

a) low value of voltage and current noise in the "flat" noise region, mainly for use as voltage amplifier A_V;
b) low value of 1/f noise, mainly for the use as charge pre-amplifier CPA followed by a long time-constant filter;
c) large ratio of g_m/I_D and low enough value of operating $V_{DS} \cdot I_D$, to minimize the power dissipation P_D;
d) large ratio of g_m/C_{ISS}, to get a large bandwidth.

Above we use the usual technical symbols.

We decided to investigate at liquid nitrogen and helium temperatures only the devices that meet the previous requirements at room temperature. After a rough selection we chose the following devices:

1.	Si JFET	2N4416A	National
2.	Si JFET	U311	Siliconix
3.	Si Dual Gate MOSFET	BF982	Philips
4.	GaAs Dual Gate MESFET	CF100	Telefunken
5.	GaAs Dual Gate MESFET	CF300	Telefunken

We have investigated the noise in the frequency range 10 kHz–50 MHz.

Moreover, to study carefully the transconductance (g_m) dependence on voltage and current biasing in stationary conditions at 300, 77 and 4.2 K, we had to develop a new type of curve tracer (5), because most of the measurements performed with a commercial one were useful only for a valuation of the devices' behaviour, not for a quantitative analysis.

In the framework of detection of Gravitational Waves (6), at 300 and 4.2 K some additional tests have been performed on several types of GaAs FETs: CF 400 (Telefunken), NE 710 (NEC), HFET 2202 (HP), MGF 1303 (MITSUBISHI). These last tests were performed in the frequency range of 1–20 MHz and the g_m dependence on the temperature measured with a conventional curve tracer. The best result was obtained with the NE 710 that at 4.2 K had a noise of ≈ 3, 1, 0.8 nV/√Hz respectively at 1, 10, 20 MHz. The value of g_m was large (≈ 60 mA/V) both at 300 and 4.2 K.

In the first section we recall the features of the GaAs MESFET; in the second we discuss the thermal effects on semiconductors at cryogenic temperatures; in the third we explain how we obtain the DC characteristics of devices; in the fourth we discuss the g_m and comparison with experimental data are suggested; in the fifth we discuss the transition capacitance, and its importance at high frequency; in the sixth we discuss the voltage noise and we show the main results; at the end, in the seventh section we just introduce a discussion on current noise measurements. A short discussion and conclusion are given in the eighth section.

1. - THE GaAs MESFET

We can consider the GaAs MESFET (Gallium Arsenide Metal Semiconductor Field Effect Transistor) as an improved version of the well known Si JFET: its operating principle is completely equivalent and the GaAs MESFET is just provided several technological improvements to increase the maximum operating frequency. Both are n channel devices because the higher mobility of electrons in comparison with holes is useful to increase the transition frequency. The improvements were performed mainly by the following:

1. using special geometry;
2. using a different technology for the gate-channel junctions;
3. using semiconducting materials exhibiting very high mobility.

About point 1., the FETs are built with channel and gate lengths as short as possible, in order to decrease the transit or delay time t_{ds} of the electrons through the channel, and with a large enough value of its width to increase the conductivity and, as a consequence, the transconductance g_m. About point 2., the improvement is obtained by the use of a metal–semiconductor (Schottky) junction between the gate and the channel. In this way the value of the gate-channel capacitance is decreased at a constant value of electron mobility. About point 3., the improvements are obtained by the use of GaAs instead of Si, as shown in Fig. 1, where the drift velocity of these two materials is plotted versus the applied electric field. Moreover, in this figure it is shown that for a constant electric field E_F, the mobility of GaAs is always higher than Si and that only for very large values of E_F are these values almost equivalent.

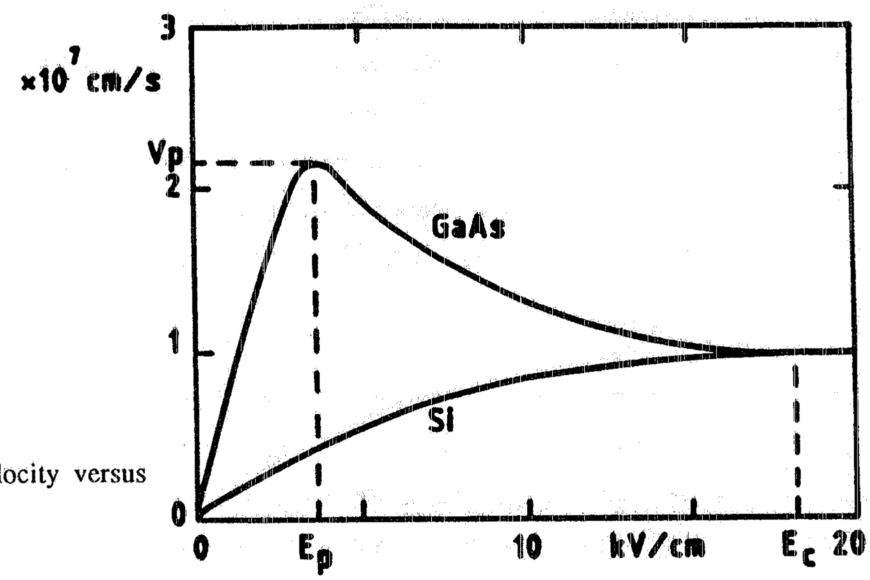


FIG. 1 - Electron drift velocity versus electric field in Si and GaAs.

The large value of electron mobility in GaAs causes, obviously, a lower value of t_{ds}. Moreover, this parameter is further decreased because of a phenomenon typical only for GaAs as follows: any electron moving in the channel of a FET is in a spatial region where the electric field intensity is, for a large factor, higher than outside. We study an electron entering in an area at high field (larger than E_p, Fig. 1) and observe how its velocity changes. We find (Fig. 2) that the electron doesn't arrive immediately to its proper speed, according to Fig. 1, but undergoes a short transition during which its speed is as large as twice the maximum value V_p at the steady state condition. This type of speed overshoot is valid only at a short distance range, of the order of a few μm. Because of this effect the high-frequency FETs have gate lengths generally shorter than 1 μm, and as a result the term t_{ds} is further reduced.

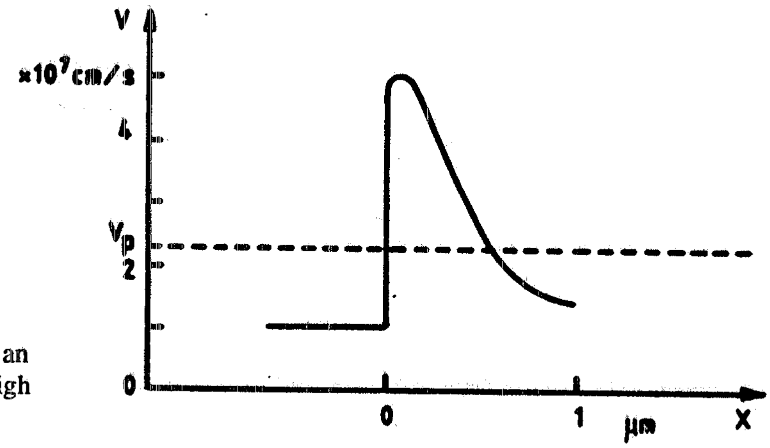


FIG. 2 - Behaviour of velocity of an electron penetrating a region of high field intensity in GaAs.

2. - THERMAL EFFECTS IN SEMICONDUCTORS AT CRYOGENIC TEMPERATURES

In any intrinsic semiconductor the electron n and hole p density is given by :

$$n = p = (N_C N_V)^{1/2} \exp(-E_g/2kT) \qquad (1)$$

for n, p << N_C, N_V,

where E_g is the energy gap of semiconductor and N_C, N_V are respectively the density of states in the valence and conduction band.

In Table I the values of E_g, at 300 and 4.2 K for the most commonly used semiconductors are reported: E_g increases by decreasing T.

TABLE I - Values of ionization and energy gaps for most commonly used semiconductors. (From Cryogenics 439, 1974; by permission of the publishers, Butterworths & Co. (Publishers) Ltd. c.)

	Si	Ge	GaP	GaAs	GaSb	InP	InAs	InSb
E_g at 4.2 K (eV)	1.153	0.744	2.325	1.517	0.813	1.416	0.425	0.236
E_g at 300 K (eV)	1.107	0.67	2.24	1.43	0.7	1.26	0.36	0.18
Donors	P, As, Sb				S, Se, T			
m_n/m_o			0.34	0.04-0.07	0.047	0.077	0.025	0.012
E_d (eV)	0.05	0.01	0.07	0.003		~0.003	0	0
Acceptors	B, Al, Ga				Zn, Cd			
m_p/m_o			0.5	0.68	0.23	0.2	0.4	0.4-0.5
E_a (eV)	0.05	0.01	0.04	0.02	0.037	0.05	0.007	0.008

The values of N_C and N_V are given by:

$$N_C = 1/4[(2m_n kT)/\pi\hbar^2]^{3/2} \qquad N_V = 1/4[(2m_p kT)/\pi\hbar^2)]^{3/2} \qquad (2)$$

where m_n and m_p are the effective masses of electrons and holes.

In an intrinsic semiconductor the ionization energies of donors and acceptors E_d and E_a determines the density of majority carriers.

In an n-type semiconductor having N_d donors and N_a acceptors per cm^3, for $N_d > 3N_a$, we have:

$$n = \{[(N_d - N_a)\cdot N_C]/2]\}^{1/2} \exp(-E_d/2kT); \quad p = [2N_C/(N_d - N_a)] \exp[-(E_g - E_d)/2kT] \quad (3)$$

From eq. (3) we deduce that the density of minority carriers is very low at low temperatures while the density of the majority ones depends exponentially on the ratio $E_d/2kT$. Moreover, Table I gives the ionization energy of donors (valence = 5) and acceptors (valence = 3) in Ge and Si. At low temperatures these energies are higher than 2kT, thus the impurities are neutralized and the free charges tend to freeze out.

The freezing out of carriers is one of major drawbacks to use Si or Ge at cryogenic temperatures. Because the value of ionization energy of the impurities in the Si is larger compared to Ge, the former is more sensitive to the freezing out of carriers. Again from Table I we can see that the ionization energy of InSb and InAs is almost zero because of the very low value of effective mass of electrons in these types of semiconductors. A low value of m_n involves a large Bohr radius for the electron, so that, even at low values of donor density ($\approx 10^{14}$ cm^3), the impurity band can rise up to the bottom of the conduction band. As a consequence, n-type InSb, InAs and GaAs, are not affected by carriers freeze-out. This effect is clearly shown in Fig. 3 where shown, versus temperature, the Hall coefficient for InSb and GaAs. We recall that R_H = 1/ne for the electrons and R_H = 1/pe for the holes. From Fig. 3 we can see that in devices of III and V groups, n-type, there are free carriers in large numbers even at 4.2 K while, for the same groups but p-type, because there is a finite value for the ionization energy of acceptors, they freeze-out.

In Fig. 4, (7) the mobility μ of Ge, GaAs and InSb versus T is shown; for any "sufficiently" doped semiconductor the maximum of μ occurs at about the same T, lower than room-temperature.

We recall that the conductivity σ is just given by: $\sigma = e(\mu_n n + \mu_p p)$ and its behaviour versus T is shown in Fig. 5. In this figure it is clearly shown that the maximum of σ is at $\approx$100 K for Si and that even at 4.2 K the value is large enough for n-type GaAs.

Summarizing, for cryogenic applications, where we can get free carriers only by thermal excitation, we have to use n-type semiconductors of the III or V groups (InSb, InAs, GaAs) or Ge and Si heavly doped.

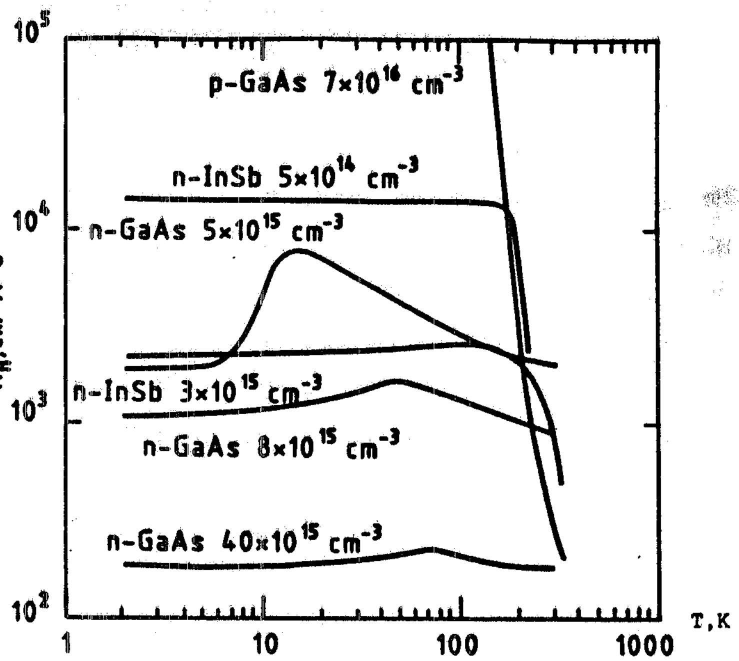


FIG. 3 - Hall coefficient versus temperature for GaAs and InSb, n and p type. (From Cryogenics 439, 1974; by permission of the publishers, Butterworths & Co. (Publishers) Ltd. c.).

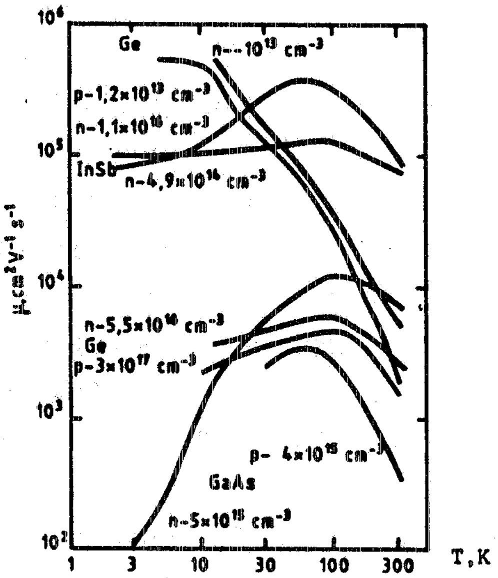
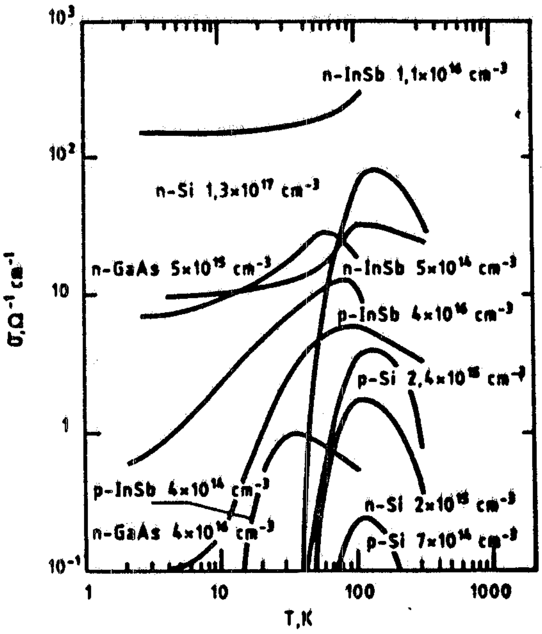


FIG. 4 - Mobility versus temperature for Si, Ge, InSb, GaAs, p and n type. (From Cryogenics 439, 1974; by permission of the publishers, Butterworths & Co. (Publishers) Ltd. c.).

FIG. 5 - Conductivity versus temperature for Si, Ge, InSb, GaAs, p and n type with different impurity concentrations. (From Cryogenics 439, 1974; by permission of the publishers, Butterworths & Co. (Publishers) Ltd. c.).



3. - FET CHARACTERIZATION

To characterize the devices, particularly their transconductance g_m, at the beginning we used a commercial curve tracer (Tektronix 7CT1N) at 300 and 77 K. Afterwards, we measured their pulsed gain, in a proper static biasing network, and we found a systematic difference between the measured and calculated values ($A_V = g_m R_L$, where g_m is the value measured with the curve tracer). In particular, the experimental values of gain were always worse at 300 K (≈ -15%) and better at 77 K (up to+40%). We realized that such large differences arise because of different behaviours of self heating effects at 300 and 77 K, so that it is impossible to make accurate measurements of g_m with these types of devices just using that type of curve tracer. The frequency (110 Hz) and wave form (triangular, < 50% duty cicle in the most favorable operating mode) are such that any measurement performed in a thermally sensitive device is inaccurate and useful only for a qualitative analysis. Using a JFET 2N4416A at V_{DS} = 10V and I_D = 10 mA, the difference was of the order of -15% at 300 K and of +30% at 77 K. The simple explanation of the phenomenon is the following: in steady-state conditions the junction temperature is always higher than in pulsed operation. The g_m dependence versus temperature for a Si JFET is always increasing with decreasing T down to a temperature of about 140 K where it begins to decrease again. Similar effects where found in other JFETs studied, while in the case of GaAs MESFETs the "error" inversion at 77 K wasn't found.

Because of this problem we developed a simple curve tracer based on a rearrangement of a FET-input True Instrumentation Amplifier (TIA) previously developed by our group (8) to study high impedance tunnel junctions. The schematic circuitry is shown in Fig. 6, where V_1/R_S is the value of drain current and V_2 is the value of V_{DS}. The input voltage to R_D is supplied by a commercial pulser (HP 8116A) and the outputs V_1, V_2 are sent to a digital plotter (HP 7090A). To make the measurements we used 4 time-constants (10 ms, 1 s, 10 s, 1000 s) always with a triangular shape. The results are shown in Fig. 7. We note that, as expected, the results with a time constant of 10 ms are completely equivalent to those obtained with the commercial curve tracer. The I-V characteristics at 1 s and 10 s show hysteresis generated by non steady-state self-heating effects, while the last one at 1000 s shows the same result (for the g_m, not shown) obtained during pulsed operation in the proper static biasing network.

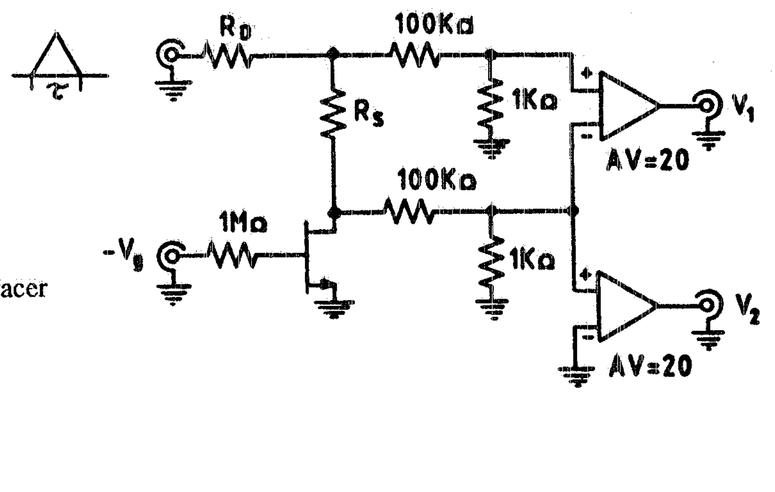


FIG. 6 - Schematic of curve tracer made with 2 FET-Input T.I.A.

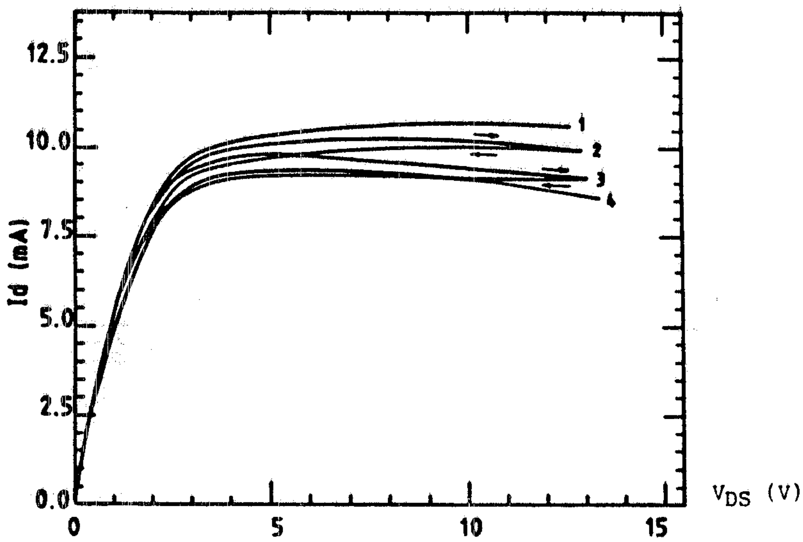


FIG. 7 - Characteristics I_D-V_{DS} of 2N4416A, at V_{gs}=0, and pulses of duration: 1=10 ms, 2=1 s, 3=10 s, 4=1000 s.

4. - THE TRANSCONDUCTANCE

The transconductance g_m in the studied devices has a very large temperature dependence and can be expressed by the following equation: $g_m = -2(I_{DSS}/V_p)\sqrt{I_D/I_{DSS}}$ where V_p is the pinch-off voltage and I_{DSS} is the drain current at V_{gs} = 0V. For decreasing T the term $g_{mo} = -2(I_{DSS}/V_p)$ increases because, at the same time, I_{DSS} increases and $|V_p|$ decreases. The term I_{DSS} increases, as shown in Fig. 5, because the conductivity increases with decreasing T: this effect causes a decreasing of channel thickness and a decreasing of $|V_p|$. In Table II the values of V_p at three different temperatures are reported.

TABLE II - Measured values of V_p, at the three operating temperatures, for the devices studied.

DEVICE	V_{DS}	V_{g2S}	$V_p(300)$	$V_p(77)$	$V_p(4.2)$	V_{CR}
2N4416A	10	_	-3.7	-3.5	N.A	-2.7V
U311	10	_	-3.65	-3.3	N.A	-3.1V
BF982	10	4	-1.25	-1.1	≈ -1	-0.95V
CF100	5	2	-2.7	-2.6	> -4	-1.9V
CF300	5	2	-3.6	-3.4	> -4	-2.85

In Fig. 8 is clearly shown the effect of V_p decreasing as T decreases: it can be observed that at 77 K I_{DSS} is always higher than at 300 K, because of larger carrier conductivity, until, with a further decreasing of V_{gs}, the effect of the increasing of the depletion region is operative. This increasing causes a sharp decreasing of I_{DS} and, as a final effect, a decreasing of V_p. The cross point V_{CR} generated by the two competitive effects is also shown in Table II.

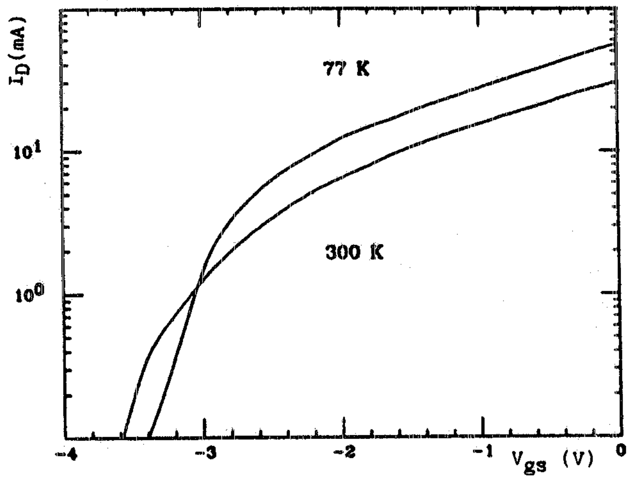


FIG. 8 - Measurements of V_p at 77 and 300 K for JFET U311. The cross point at -3.1 V arises from two competitive physical effects, see text.

Another effect at LN_2 is a noticeable increasing of g_m induced by self-heating effects in JFETs. As a final effect g_m increases, at constant I_D, increasing V_{DS}. This effect is poorly evident in GaAs MESFET because of the almost constant conductivity of GaAs in the region of 100 K. Moreover, the self-heating effect isn't evident for the Si MOSFET because, for this particular type of device, the charge carriers arise from field effects and not from thermal effects like in JFETs. In particular, this is the reason why a Si MOSFET can work down to 4.2 K although its conductivity arising from thermal effect is almost zero.

The results of our measurements are shown in Figs. 9, 10.

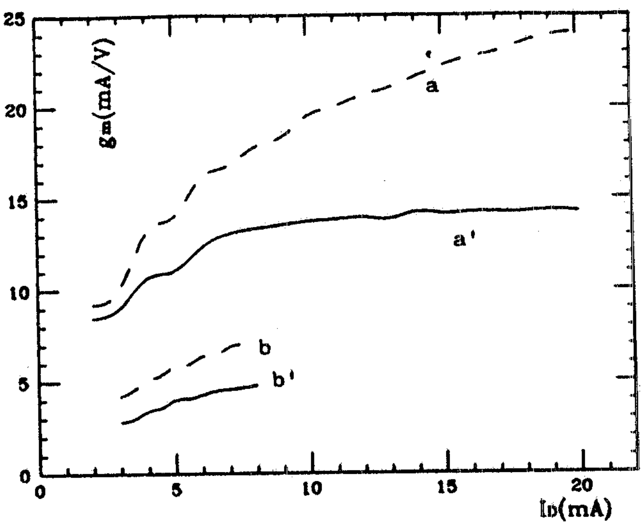


FIG. 9 - Transconductance of JFET U311 (a,a') and 2N44164 (b,b') at 77 K (dashed) and 300 K.

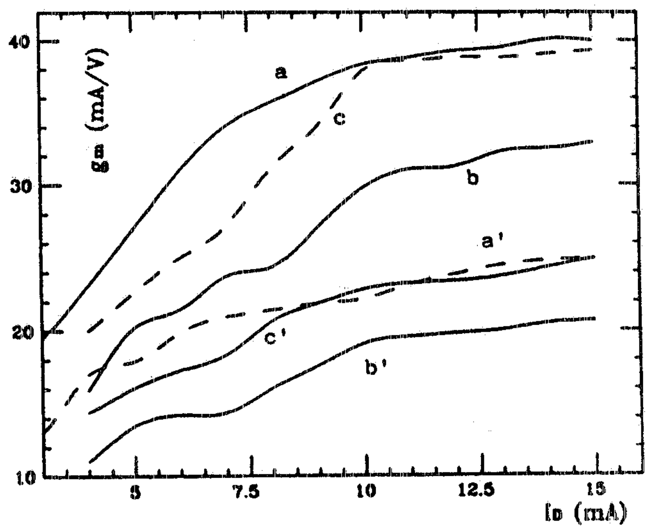


FIG. 10 - Transconductance of BF982 (a, a'), CF100 (b,b') and CF300 at 77 K and 300 K. The g_m at 77 K is always larger than at 300 K.

We note that at the LHe^4 temperature both the Si JFETs pratically didn't operate (the g_m of the U311 was as low as 1 mA/V), the MOSFET BF982 was not stable and both types of GaAs MESFET had "middle" behaviours not substantially different from 77 K, except the values of g_m

were similar to that of 300 K. About the GaAs MESFETs we note that at 4.2 K the performances are strongly device dependent and a selection is needed to find the right one for the use at LHe^4 while at LN_2 the selection isn't necessary. We hypothesize that this behaviour can arise from the thermo-mechanical stress in the plastic package and from a noticeable variation of conductivity according to Fig. 5.

5. - TRANSITION CAPACITANCE

For our purpose an important parameter is the cut-off frequency. Its expression is:

$$f_{cut\text{-}off} = g_m/C_{ISS}, \qquad \text{where} \quad C_{ISS} = C_{gs}+C_{gd}.$$

The measurements were performed using the circuit of Fig. 11 varying the value of R. In this circuit the input and output time constants τ_1 and τ_2 are given by:

$$\tau_1 = C_{in}(R+50\Omega); \qquad \tau_2 = R_d(C_{gd}+C_d)$$

where

$$C_{in} = C_{gs}+(1+A_V)C_{gd}; \qquad C_d = \text{probe capacitance.}$$

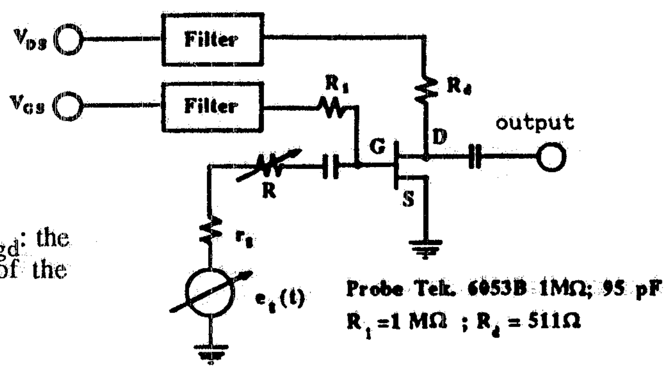


FIG. 11 - Circuit for the measurement C_{gs} and C_{gd}: the amplitude of the output signal as a function of the frequency of the generator $e_g(t)$ is analyzed.

The decreasing of C_{in} with the decreasing of T is noticeable. This effect arises because C_{in} has the same qualitative temperature dependence as the transition capacitance C_t which is given by: $C_t = \varepsilon A/W$, where ε is the dielectric constant, A is the junction area, W is the thickness of the depletion region. As stated before, the term W increases with decreasing T.

In Table III are reported the calculated values of $f_{cut\text{-}off}$ using the measured value of C_{ISS}.

TABLE III - Calculated values of cut off frequency using the measured values of C_{ISS}.

DEVICE	I_d(mA)	V_{ds}(V)	V_{g2s}(V)	f(300)(GHz)	f(77)(GHz)
2N4416A	10	10	_	1.6	3.32
U311	10	10	_	2.8	6.47
BF982	15	10	4	6.5	10.8
CF100	10	5	2	14.48	24.19
CF300	10	5	2	21.3	35.8

The results of measurements performed at 300 K and 77 K are shown in Figs. 12, 13 and are self explanating. We just recall that it was impossible to make measurements of C_{gd} on MOS and GaAs because of their extremely low values (fF region): this leads to calculated $f_{cut-off}$ larger than the measured values.

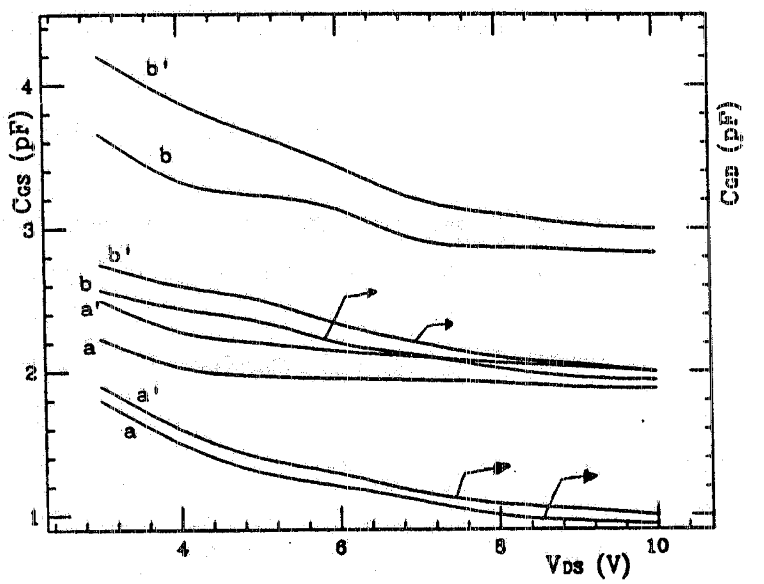


FIG. 12 - The measured values of C_{gs} and C_{dg} for the devices:
1) 2N4416A at 77 K (a) and at 300 K (a');
2) U311 at 77 K (b) and at 300 K (b').

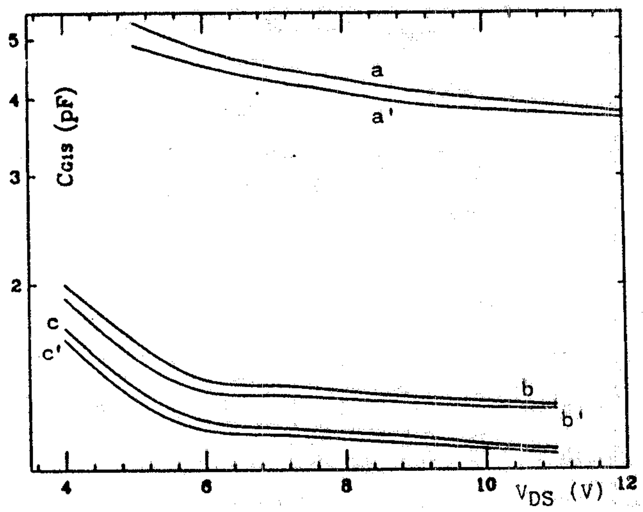


FIG. 13 - Behaviours of C_{gs} vs V_{DS} for BF982 (a,a'), CF100 (b,b') and CF300 (c,c') at 77 and 300 K. The values of C_{gs} at 77 K are always better (i.e. lower) than at 300 K.

6. - VOLTAGE NOISE

According to the usual theoretical model, any type of active device, from the point of view of noise, can be schematized as a noiseless network with a proper voltage noise generator (e_n) in series plus another current noise generator (i_n) in parallel. The term e_n arises because of completely random temperature-dependent fluctuations in the channel (it is called thermal or Johnson noise). This type of noise is schematized as following: $e^2_n = V^2_n/B = 4kT\gamma/g_m$, where k is the Boltzmann constant, T the channel temperature of the FET, B the bandwidth of measurement and γ an experimental coefficient whose value is device "family" dependent and usually ranges between 0.6 and 0.7. The spectral density of this noise is constant and it is also called "white noise".

Below some proper frequency f_c, usually called corner frequency, the JFET has an excess noise with a spectral density of the type $e_{nc} = 1/f^{\alpha}$ with α almost unity. The corner frequency is a function of the device studied and, theoretically, temperature dependent. We remark that in our measurements we find just a slight temperature dependence of f_c, and a large dependence of the absolute value of the noise. This type of noise is justified as arising from traps, in the channel and depletion region, causing an increasing of generation and recombination noise. According to the fundamental work of Van der Ziel (9) the spectral density of an equivalent noise generator, because of generation and recombination in the channel, is given by:

$$e_{gr1}{}^2 = KP\tau/(1+\omega^2\tau^2) \qquad (4)$$

where K is a constant depending on donor concentration geometry in the device and on its temperature; $P = V_{DS}\cdot I_{DS}$ is the power dissipated in the channel and τ is the average time of recombination and generation process and is temperature dependent.

About the generation and recombination noise due to traps in the space charge region, it is possible to show (10) that the spectral density of this type of noise generator is given by:

$$e_{gr2} = AN_t\tau Ff_t(1-f_t)/(1+\omega^2\tau^2) \qquad (5)$$

where A is a constant depending on device geometry, N_t is the trap density in the depletion region, F depends on the biasing point, f_t is the fraction of free traps. This type of noise is mainly due to τ, which is temperature dependent and at room temperature the e_{gr2} value is larger than the other one due to traps in the channel (e_{gr1}).

MOSFET devices are completely different from JFETs: they are essentially surface effect devices and the physical process causing noise at low and middle frequency is completely different. In this type of device the "flicker noise" arises from tunneling of carriers between the gate surface and the traps in the oxide (11, 12) and/or random fluctuations of the carriers in the surface and in the bands (13, 14).

The noise measurements were performed in the frequency range 10 kHz–50 MHz. The measurements were carried out with the following instruments:

1. Spectrum Analyzer HP 141T with RF section mod. 8553B (1 kHz–110 MHz);
2. Low noise preamplifier mod. E103 from Comlinear Corp. (BW = DC–100 MHz) gain ≈ 30 db;
3. Home-made preamplifier based on 3 selected SILICONIX FET U311 always immersed in LN_2 for low noise purposes; BW = 1 kHz–70 MHz, gain ≈ 20 db. This amplifier was the front-end for all the device studied.

The drain, as usually, was loaded by a resistor which has in series an inductance connected to the power supply.

In all measurements we used metal-oxide type resistors, 1/4 W, from SFERNICE, model RCMS05K. In the most critical points, silver-mica type capacitors from MIDWEC were inserted. As inductors we used the model 4322.057 from Philips.

The values of drain resistance and inductance are listed in Table IV at the three studied temperatures.

TABLE IV - Values of load on the drain of devices studied.

DEVICE	$R_d(\Omega)$	$L_{D(300\,K)}(\mu H)$	$L_{D(77\,K-4.2\,K)}(\mu H)$
2N4416A	464	1	0.8
U311	464	1	0.8
BF982	636	0.8	0.33
CF100	636	0.3	0
CF300	636	0.3	0

The voltage noise arising from the devices was calculated using conventional noise-composition formulas. The results are reported in Figs. 14, 15, 16.

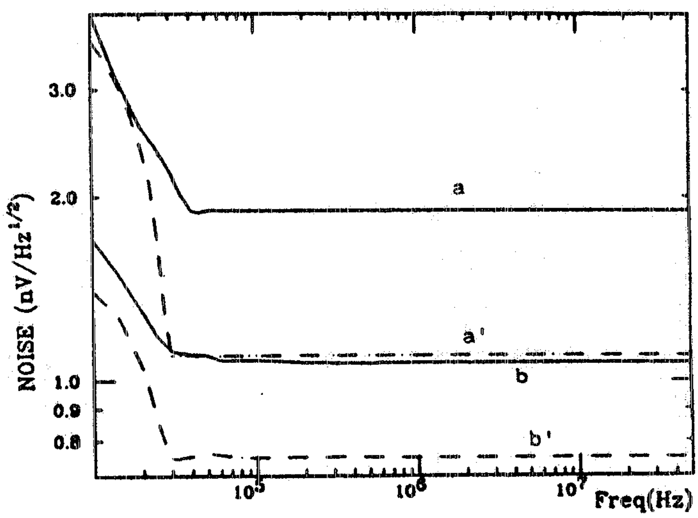


FIG. 14 - Voltage noise vs frequency of JFET 2N4416A (a,a'), and U311 (b,b') at 77 and 300 K. The values are always better (i.e. lower) than at 300 K.

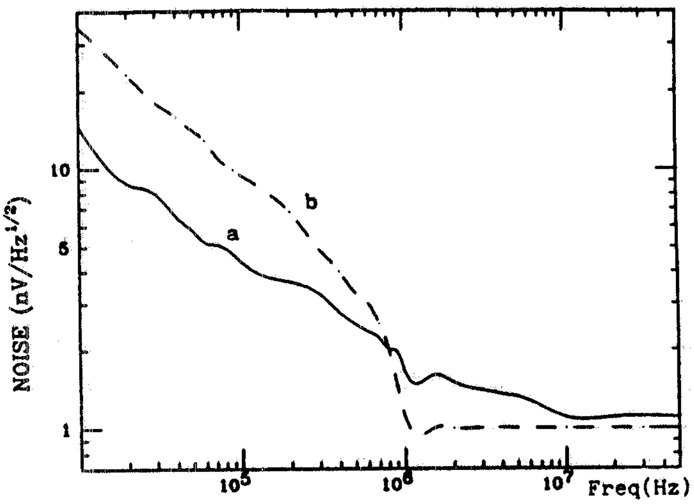


FIG. 15 - Voltage noise of MOSFET BF982 at 77 K (a) and 300 K (b). In this case the behaviours at low and high frequencies are different because of competitive effects, see text.

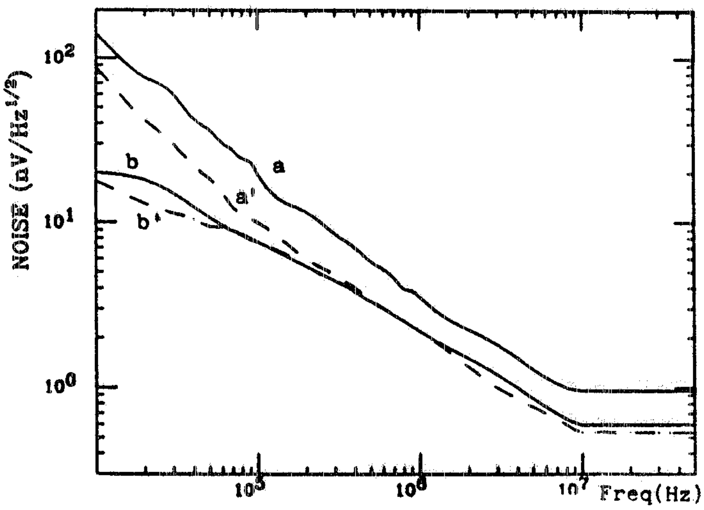


FIG. 16 - Behaviour of voltage noise vs frequency at 77 and 300 K of CF100 (a,a') and CF300 (b,b'). The values at 77 K are always better (i.e. lower) than at 300 K.

7. - CURRENT NOISE

The current noise term wasn't of concern to us, because of low values of the output impedance in our particular application; anyway we checked that for an input resistance as large as 10 KΩ the value of the current noise component was always noticeably lower than the voltage noise at any frequency or temperature investigated.

8. - CONCLUSIONS

We have demonstrated that, for large enough values of power dissipated by the device (100 mW), the voltage noise and gain of Si JFETs is always better at 77 K than at 300 K. In particular, for the JFET U311 we got an improvement of g_m of about 70% with a noise reduction of about 30%. The value of voltage noise found is remarkably low (≈0.75 nV/√Hz) and flat from 30 kHz to over 50 MHz.

About the MOS BF982, according with the theory, the performance at 77 K, in some frequency range, is worse than at 300 K. Anyway, it has low enough noise (≈ 1 n V/√Hz at 1 MHz), large transconductance (40 mA/V at 77 K), and a low value of input capacitance.

About the GaAs CF300, power dissipated "only" 50 mW, we have very good results because at 77 K we measured a voltage noise of just ≈ 0.55 nV/√Hz at 10 MHz and about 3 nV/√Hz at 1 MHz. Considering its large value of transconductance (38 mA/V) and extremely low value of input capacitance, this is a promising device for many medium-high frequency cryogenic applications after selection for operation at LHe^4. Last but not least, its price is remarkable low (<2 US$) when compared to other competitive GaAs devices.

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