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THE MAIN CHARACTERISTICS OF SIGE HBTS AT LOW TEMPERATURES[1]

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ОСНОВНІ ХАРАКТЕРИСТИКИ SIGE ГЕТЕРОПЕРЕХІДНИХ БІПОЛЯРНИХ ТРАНЗИСТОРІВ ПРИ НИЗЬКИХ ТЕМПЕРАТУРАХ

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Introduction

The analog integrated circuits (IC), operating at low temperatures up to the temperature of liquid nitrogen, are widely used in different areas: research tool engineering, cryogenic instrumentation and medical devices, scientific instruments for the Arctic and Antarctic Regions. In case, when the low-temperature analog ICs are designed to detect the extreme small signals of various sensors of particles, ionizing and optical radiation, the silicon JFET is more often used as a head low-noise transistor, in others the silicon MOS transistors or SiGe BiCMOS are mostly used [1-3].

It should be noted, that BiCMOS SiGe technology is in high demand as it allows creating complex systems-on-a-chip, including either microwave SiGe bipolar functional blocks or CMOS processors and other digital devices [4]. Besides, the hardware components, created on the BiCMOS SiGe technologies, are highly resistant to the effects of penetrating radiation [5].

These factors explain why the low-temperature research of characteristics of SiGe transistors is of great interest and why there are a lot of publications about them. Let's emphasize the most important among them [6-8].

Unfortunately, in the carried out investigations [9-13] the studies of the main CVCs of SiGe HBTs within the temperature range up to minus -195˚C, which

[1] http://radap.kpi.ua/radiotechnique/article/view/1340

determine the static parameters and the performance of the analog ICs, are downplayed.

The aim of this article is to discuss the results, obtained in the experimental studies, which are especially important for the analog IC low temperature features of SiGe BTs, including

- the dependences of static base current gain β_F on the collector current I_C and the collector-to-base voltage Ucb;
- the dependences of I_C and the base current I_B on the base-to-emitter voltage Ube (Gummel's plots);
- the output CVC in the CEC, i.e. the dependences of Ic on the collector-to-emitter voltage Uce at the preset Ib.

The Study Samples and the Measurement Technique

The test chip SGB25V_019P, which consists of four n-p-n transistors of n-p-nH type, connected in parallel, and two polysilicon resistors with the resistance close to 3 kiloohm is studied. Each transistor has 16 emitters with the size of 0.42x3.36 μm^2, located in the form of the matrix 8x2. The test chip is produced on the technology of 0.25 µm SiGe BiCMOS of SGB25V type and assembled into the package 5140.8-AH3 with the capacity of the current-carrying elements not higher than 3 pF. The sample structure of the transistor is shown in Fig. 1 [5], and the main parameters of the n-p-nH type transistor are presented in Table 1 [14].

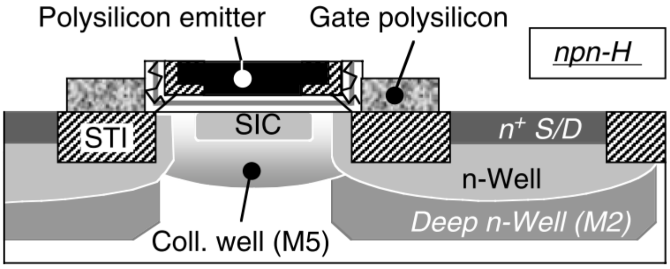


Fig. 1. The sample structure of the transistor of n-p-nH type produced on the SGB25V technology of IHP [14].

The low-temperature measurements are carried out on the experimental setup, given in Fig. 2. The measured transistors are located in a metal glass, placed in the liquid nitrogen with the help of a rod (Fig. 3) with a wire harness of twisted pairs inside for connection to the semiconductor item tester SCIT-1 IPPP-1. The measured data are delivered to the personal computer (PC) through the RS-232 interface.

Table 1: The main parameter of the transistor of n-p-nH type [14]

Name of the parameter	Value
Size of the emitter, A_E	0.42x0.84 μm^2
Peak cut-off frequency, f_T	25 GHz
Collector-to-emitter breakdown voltage, BU_{CE0}	7.0 V
Collector-to-base breakdown voltage, BU_{CB0}	>20 V
Early's voltage, U_A	>100 V

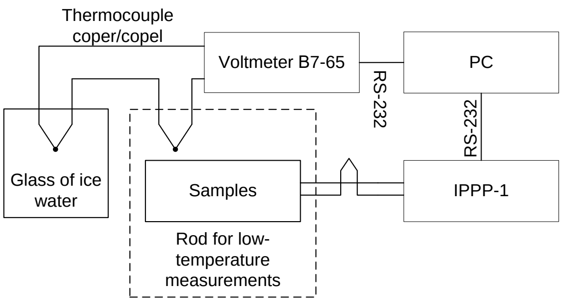


Fig. 2. The circuit of the experimental setup for the low-temperature measurements.

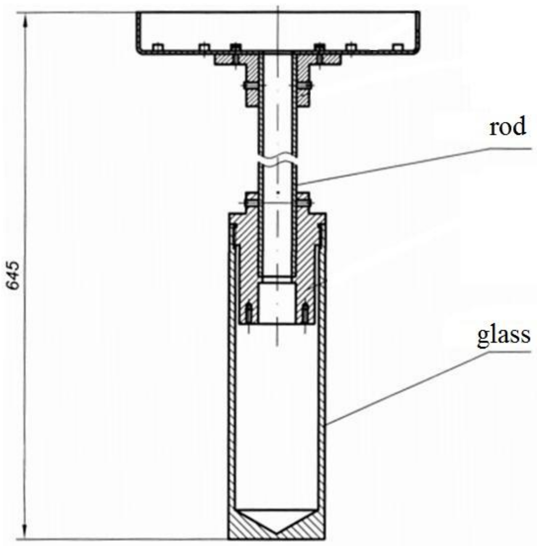
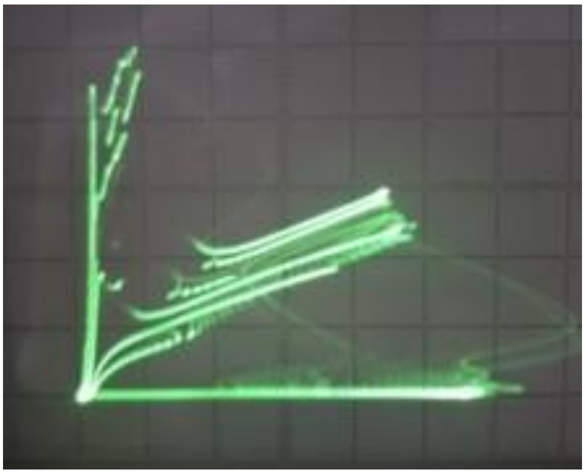


Fig. 3. The fixture for the low-temperature measurements.

The thermocouple of M type, defined in the Standard-P 8.585—2001 (Coper/Copel), is used to control the temperature. It is located close to the measured transistors. The temperature is registered by the "cold junction compensation" technique, at which an exposed end of the thermocouple is placed in the glass with water and floating ice (in Fig. 2 it is marked as a "glass of ice water"). The thermal emf of the thermocouple is fixed by the voltmeter B7-65 and is delivered to the PC through the RS-232 interface. The measurements are carried out in the automatic mode under the control of the program in "VEE Pro" environment.

To eliminate the effect of the self-excitation of transistors the preparations are carried out with the help of the transistor curve tracer L2-56 before the beginning of the low-temperature measurements.

Thus, Fig. 4a gives a photo of the output CVC in the CEC of the n-p-n transistor SGB25V_019P, directly connected with L2-56, and Fig. 4b presents a photo of the same transistor, where the inductance coil with the resistance of 0.1 Ohm and the inductance of 50 μHY is connected to the collector circuit.



a)

b)

Fig. 4. The photo of the output CVC in the CEC of the n-p-n transistor SGB25V_019P, registered by the transistor curve tracer L2-56: a – a direct connection of the transistor with L2-56; b – an inductance coil with the resistance of 0.1 Ohm and the inductance of 50 μHY is connected to the collector circuit.

The final circuit of connection of the measured transistors to the IPPP-1 is shown in Fig. 5, by the way, the values of the resistance Rb, the capacitance C1 and the parameters of the inductance coils L1-L3 are chosen to eliminate the self-excitation of transistors, connected with the tester by a long twisted pair. Besides:

- one electrical conductor of the screened twisted pair is connected to each output: N1, N2, N3, and the second electrical conductor and the screen are grounded;
- the capacitor C1 without pins, located as close as possible to the package of the studied sample, is used;
- the resistor Rb of CP-25 type and the filter CB6A-830263 with a ferrite core are applied.

Let's note that R1, R2 are polysilicon resistors, located on the test chip. They are a resistance divider entered between the pins of the positive VCC and negative VEE voltage supplies. This divider is designed for setting the base potential of the SiGe transistor.

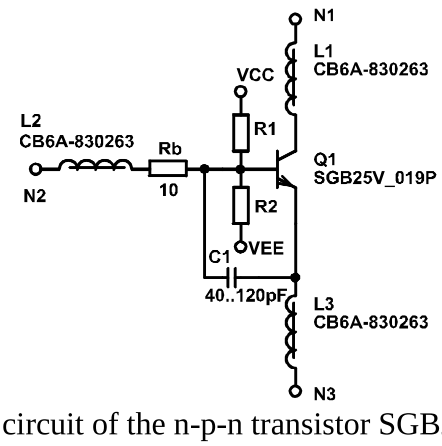


Fig. 5. The connection circuit of the n-p-n transistor SGB25V_019P at the remote measurements of CMC within the temperature range from 27°C up to minus -195°C.

The low-temperature measurements are carried out in the following way:

- to carry out the low-temperature measurements (Fig. 3) the samples of the measured transistors are placed in the metal glass of the fixture, which is completely embedded in the liquid nitrogen;
- the temperature in the glass is measured with the help of the thermocouple, and when the temperature reaches the value minus -195±5˚C, the measurements of the transistors are carried out;
- the glass of the fixture is lifted to be partially covered by the liquid nitrogen, and next measurements of transistors are carried out, when the temperature level is higher than the temperature of the liquid nitrogen.

Measurement Data

Fig. 6-9 give typical temperature dependences, which are the most important for designing the analog ICs.

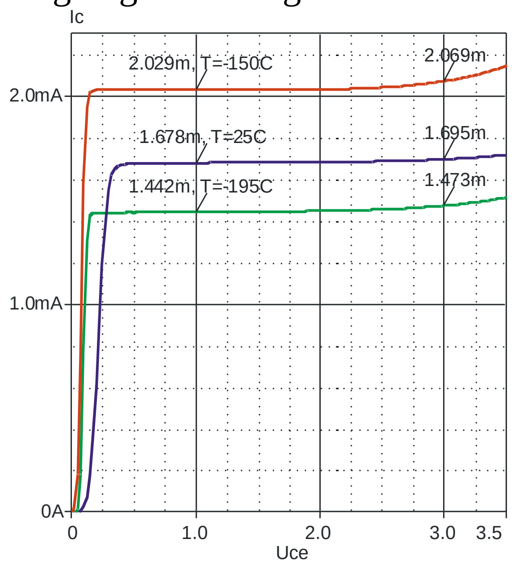


Fig. 6. The dependence of Ic on Uce, when Ib=8 uA within the temperature range.

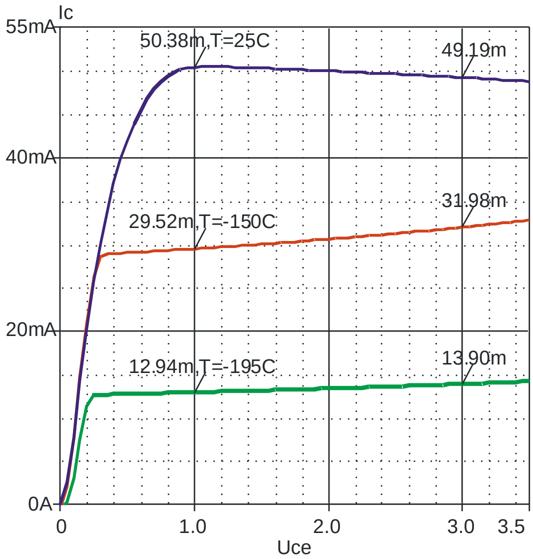


Fig. 7. The dependence of Ic on Uce, when Ib=300 uA within the temperature range.

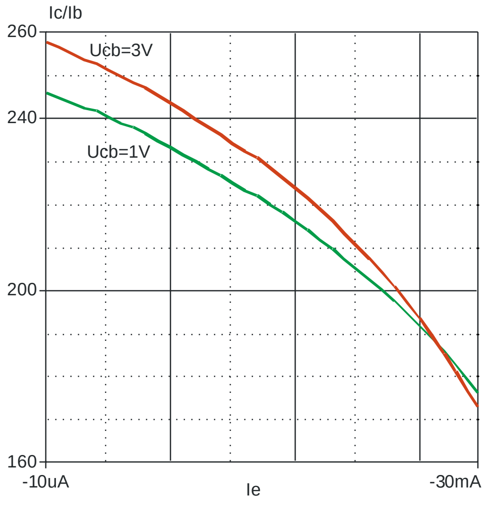


Fig. 8. The dependence of β_F =Ic/Ib on Ie, when Ucb = 1; 3 V (T = 25˚C).

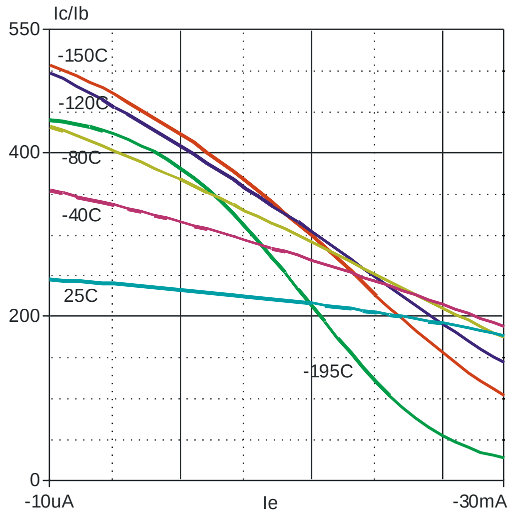


Fig. 9. The dependence of β_F on Ie, when Ucb = 1 V within the temperature range.

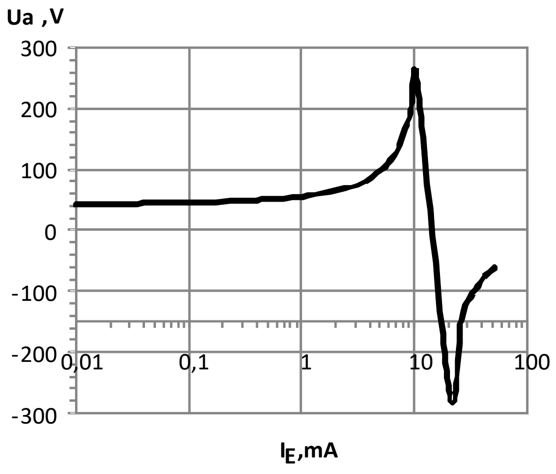


Fig. 10. The dependence of the Early's voltage (Ua) on Ie, when T = 25˚C.

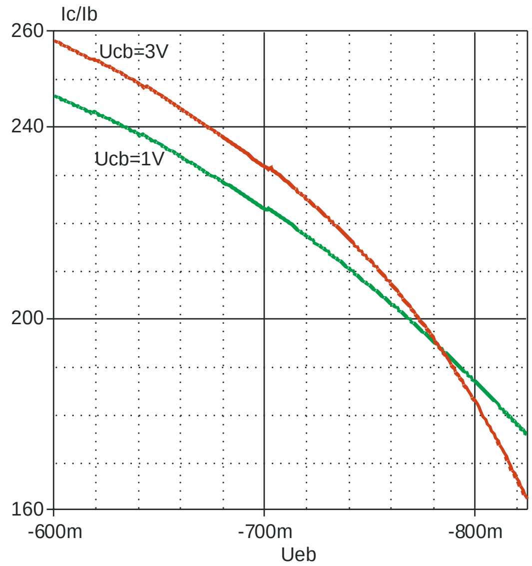


Fig. 11. The dependence of β_F on Ueb, when Ucb = 1; 3 V (T = 25˚C).

The analysis of the obtained results allows determining the following features of CVCs of SiGe n-p-n- transistors of the SGB25V technology:

1. As it is seen from the Gummel's plots, the average value of the thermal coefficient of the forward voltage drop on the emitter junction within the temperature range from minus -195˚C up to 25˚C is minus -1.75 mV/˚C.

2. The weak dependence β_F=f(Ie) is determined, when T = 25˚C, and at low temperatures the increase of β_F at small Ie and the fall of β_F at large Ie are fixed (Fig. 9). Such temperature change of β_F coincides with the results, given in [10].

3. In the output CVC in the CEC in the region of large currents (Fig. 7) at the temperature 25˚C there is a region of negative differential collector resistance r_{COUT}=dIc/dUce<0. There is no such effect at other studied temperatures. It should be noted, that this effect is observed in various SiGe n-p-n transistors, but in different regions of the collector currents and temperatures [10, 12]. In a quality manner r_{COUT} <0 can be described by the negative value of the Early's voltage (Ua), i.e. [15]:

$$Ua \approx r_{COUT} \cdot |Ic|. \quad (1)$$

4. When T = 25˚C, we observe the increase of β_F at the enlargement of Ucb in the region of small emitter currents, and we can determine the decrease of β_F at the growth of Ucb in the region of large emitter currents (Fig. 8). This effect can also be described by the negative value of Early's voltage [15]:

$$\mathrm{U}a \approx \frac{\mathrm{Ucb}_2 - \mathrm{Ucb}_1}{\beta_{F2} - \beta_{\mathrm{F1}}} \beta_{\mathrm{F1}}, \quad (2)$$

where β_{F1}, β_{F2} are values of the parameters at the voltage Ucb_1, Ucb_2 correspondingly.

The calculation results of the dependence of Ua=f(Ie) at T = 25˚C are given in Fig. 10, where there is a large region of almost constant Ua, and then the fast growth of Ua and the change of its polarity.

For validation of the measurement results, presented in Fig. 8, from the Gummel's plots we obtain the dependence β_F=f(Ucb, Ube) (Fig.11), which occurs very close to the diagrams of Fig. 8, considering, that the extreme values of Ube in Fig. 11 correspond to the collector current, equal to 10 uA and 30 mA.

When designing the low-temperature analog ICs it is important to know the effect of the temperature on the capacitances of p-n-junctions and the temperature resistance coefficient of the resistors TR:

$$TR = \frac{\frac{R_T}{R_N} - 1}{T - T_N}, \qquad (3)$$

where R_T, R_N are resistances of the resistor at the current T and nominal T_N temperature.

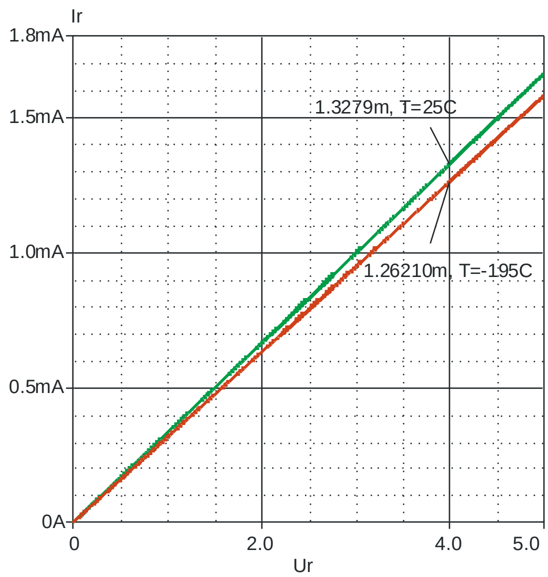


Fig. 12. Sample CVC of polysilicon resistor at T = 25˚C, minus -195˚C.

As it follows from Fig. 12, 13, the polysilicon resistors of the test chip SGB25V_019P are characterized by high linearity of CVC and low negative temperature coefficient, the absolute value of which increases with the decrease of the temperature.

Let's note that the capacitance of the emitter junction (Fig.14) decreases by a factor of 3.44 when the temperature decreases from 25˚C to minus -195˚C.

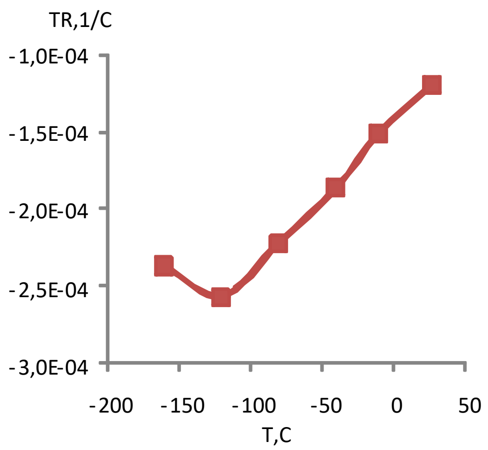


Fig. 13. The dependence of the temperature resistance coefficient of the polysilicon resistor on the temperature.

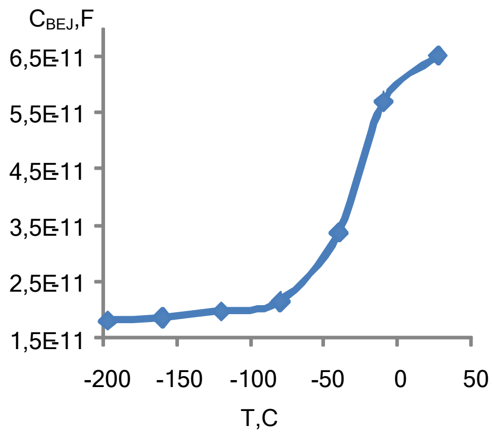


Fig. 14. The dependence of the capacitance of the emitter junction C_{BEJ} on the temperature at Ueb = 0.

Conclusion

When carrying out the low-temperature measurements of the high-frequency SiGe HBTs, connected with the measuring systems by a long cable, a special attention should be paid to the elimination of the transistor self-excitation. For this purpose it is recommended to connect the low-pass filters, the capacitor, shunting the emitter junction, and the resistor with a small resistance in a base circuit as close as possible to the pins of the base, emitter and collector.

For the test transistor SGB25V_019P, produced by IHP, we determined a weak dependence β_F=f(Ie) at T = 25˚C, the increase of β_F at small Ie and the fall of β_F at large Ie at low temperatures, the presence of the region of negative differential collector resistance.

The carried out studies allowed drawing conclusion that the most widespread model of HBT of Gummel-Poon describes the characteristics of SiGe HBTs improperly in a wide temperature range. It is expedient to use the obtained experimental data for identification of the parameters of the HBT model MEXTRAM.

However, despite the mentioned features, SiGe HBTs, produced on the SGB25V technology of IHP, can be used for design of the high-quality and low-temperature analog ICs.

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Dvornikov O. V., Tchekhovski V. A., Dziatlau V. L., Prokopenko N. N. ***The main characteristics of SiGe HBTs at low temperatures.*** *The current-voltage curves (CVC) of n-p-n SiGe heterojunction bipolar transistors (HBT) are considered within the temperature range from minus -195˚C up to 25˚C, produced on the SGB25V technology of IHP. The experimental setup, the measurement technique and the connection features of transistors for elimination of the self-excitation are described. The special attention is paid to the temperature dependences of the static base current gain* β_F *in the common-emitter configuration (CEC) and to the output CVC characteristics of transistor in the CEC.*

Keywords: *SiGe bipolar transistors, low temperatures, temperature of liquid nitrogen*

Дворніков О. В., Чеховський В. О., Дятлов В. Л., Прокопенко М. М. ***Основні характеристики SiGe біполярних гетеротранзисторів за низьких температур.*** *Розглянуті вольт-амперні характеристики (ВАХ) n-p-n SiGe біполярних транзисторів (БТ) в діапазоні температур від мінус 195˚С до 25˚С, що виготовлені по технологічному маршруту SGB25V фірми IHP. Описана експериментальна установка, методика вимірювань і особливості ввімкнення транзисторів для усунення ефекту самозбудження. Особливу увагу приділено температурним залежностям статичного коефіцієнту підсилення струму бази в схемі з спільним емітером* β_F *і вихідної ВАХ транзистора в схемі з спільним емітером.*

Ключові слова: *SiGe біполярні транзистори, низькі температури, температура рідкого азоту.*

Дворников О. В., Чеховский В. А., Дятлов В. Л., Прокопенко Н. Н. ***Основные характеристики SiGe гетеропереходных биполярных транзисторов при низких температурах.*** *Рассмотрены вольтамперные характеристики (ВАХ) n-p-n SiGe биполярных транзисторов (БТ) в диапазоне температур от минус 195˚С до 25˚С, изготовленных по технологическому маршруту SGB25V фирмы IHP. Описана экспериментальная установка, методика измерений и особенности включения транзисторов для устранения эффекта самовозбуждения. Особое внимание уделено температурным зависимостям статического коэффициента усиления тока базы в схеме с общим эмиттером (ОЭ)* β_F *и выходной ВАХ транзистора в схеме ОЭ.*

Ключевые слова: *SiGe биполярные транзисторы, низкие температуры, температура жидкого азота*