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THE RESEARCH OF LOW-NOISE GAN HEMT OF CRYOGENIC TEMPERATURES

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ИССЛЕДОВАНИЕ МАЛОШУМЯЩИХ GAN HEMT ПРИ КРИОГЕННЫХ ТЕМПЕРАТУРАХ

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Annotation

The article presents the results of a research of the possibility of using discrete devices based on gallium nitride of the centimeter wavelength range for receivers of space systems and as part of ground-based radio astronomy observation systems using cryogenic cooling units.

Аннотация

В статье представлены результаты исследования возможности применения дискретных приборов на основе нитрида галлия сантиметрового диапазона длин волн для приемных устройств космических систем и в составе наземных комплексов радиоастрономического наблюдения космического пространства, использующих криогенные охлаждающие установки.

Key words: GaN HEMT, low-noise, cryogenic temperature
Ключевые слова: GaN HEMT, малошумящий, криотемпература

Introduction

In the last decade, in Russia and the world there has been a sharp increase in interest in transistors based on gallium nitride structures - the devices have been mastered in serial production. Devices based on such structures are used as part of microwave amplifiers for ground, sea, airborne and space-based systems, and transceiver modules and amplifiers for space-based radio-electronic systems are commercially available and developed. Transistors and monolithic integrated circuits made by gallium nitride technology, compared with analogs made by gallium arsenide technology, have a number of main advantages [1]:

- high breakdown voltages (up to 300 V for microwave transistors and up to 1200 V for power devices);
- high specific power (up to 10 W/mm for serial devices);
- high thermal conductivity and operating temperatures;
- high radiation resistance and reliability.

Record specific power is one of the main achievements for GaN-based devices due to high breakdown voltages, which in combination with a high current density provides an output power level of up to 10 watts per 1 millimeter of gate width, which is an order of magnitude higher than analogs based on gallium arsenide.

In addition, the structural features of substrates based on gallium nitride heterostructures make it possible to work not only with high output power levels, but also to withstand significant input power levels (up to 5 W / mm), which is an order of magnitude higher than gallium arsenide structures [2]. Given this, as well as the presence of a high gain, it is of interest to use GaN HEMT in the input low-noise amplifiers of the centimeter and millimeter frequency ranges without the use of special protection circuits, which in turn will allow receiving devices with low values of noise figure and resistant to synchronous and non-synchronous high power levels. Использование подобных устройств особенно важно в радиоэлектронных системах с АФАР [3]. Another area of application of GaN HEMT is their application in space-based equipment, characterized by high requirements for resistance to special factors of outer space and a wide range of operating temperatures, including low temperatures of cryogenic levels.

Progress in the development of electronic components based on gallium nitride for receiving devices has been restrained for many years by both the shortcomings of the substrates themselves and the imperfection of the epitaxial structures grown on them. Substrates for the epitaxial growth of gallium nitride layers should have a minimum difference in lattice parameters, high thermal conductivity, and insulating properties. Researches show that to increase the limiting frequencies, thinner heterostructures should be used, the permissible barrier thickness of which sharply increases with an increase in the cutoff frequency [4].

Devices manufactured using GaN technology are steadfast to structural damage. Dose effects in galium nitride structures begin to appear at sufficiently high levels, because they primarily appear in the dielectric layers of the device structures, and only at very high levels of exposure does the contribution of various physical effects become significant, which cause the rearrangement of charge states in the active regions of the devices. Dose rate effects are manifested in GaN transistors to a much lesser extent in comparison with silicon, silicon-germanium, and gallium arsenide devices, due to the wider band gap - 3.4 eV. The absence of parasitic four-layer structures fundamentally excludes the possibility of activation of the thyristor effect. Catastrophic failures in GaN transistors when exposed to heavy charged outer space with linear energy losses of up to 80 MeV·cm^2 / mg of particles do not occur [5].

In [6–9], processes and methods for optimizing the design of the heterostructure and HEMT are presented, aimed at reducing the noise temperature of devices based on AlGaN/GaN.

Formulation of the problem

Experience in cooling a GaAs HEMT dies to cryogenic temperatures showed that freezing of phonons and a decrease in the cross section of a “two-dimensional electron gas” in semiconductor structures based on gallium arsenide leads to an increase in the internal slope of the active element and to a decrease in parasitic active and reactive resistances. These changes entail not only a decrease in the noise figure and an increase in the gain of the transistor, but also lead to a decrease in the matching band and a decrease in the stability coefficient, which was necessary to take into account when designing cooled amplifiers, since the optimal matching circuits of the transistor at cryogenic temperatures, as a rule, do not coincide with optimal matching network under normal conditions, and vice versa. That is why it was decided to research the behavior of GaN HEMT at cryogenic temperatures.

The research of the possibility of using low-noise devices based on gallium nitride for use at cryogenic temperatures was carried out on discrete GaN HEMT manufactured by S&RE Pulsar JSC and MIC based on them in the centimeter wavelength range.

Research results

At the initial stages of the work, it was necessary to determine the stability of GaN HEMT at cryogenic temperatures and when temperatures change: stability, the nature of the change in noise temperature and gain, the influence of power modes, etc. For the research, a transistor manufactured by S&RE Pulsar JSC with Wg = 150 μm was selected. The appearance of the test transistor is shown in Fig. 1.

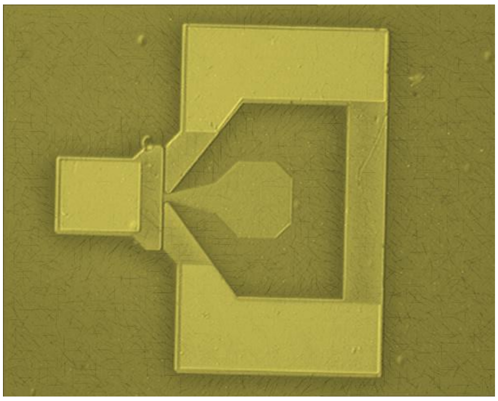

Fig. 1 Appearance of a test transistor

The block diagram of the cryogenic measuring installation is shown in Fig. 2. A closed cooling system allows reaching the base temperature T = 22 K.

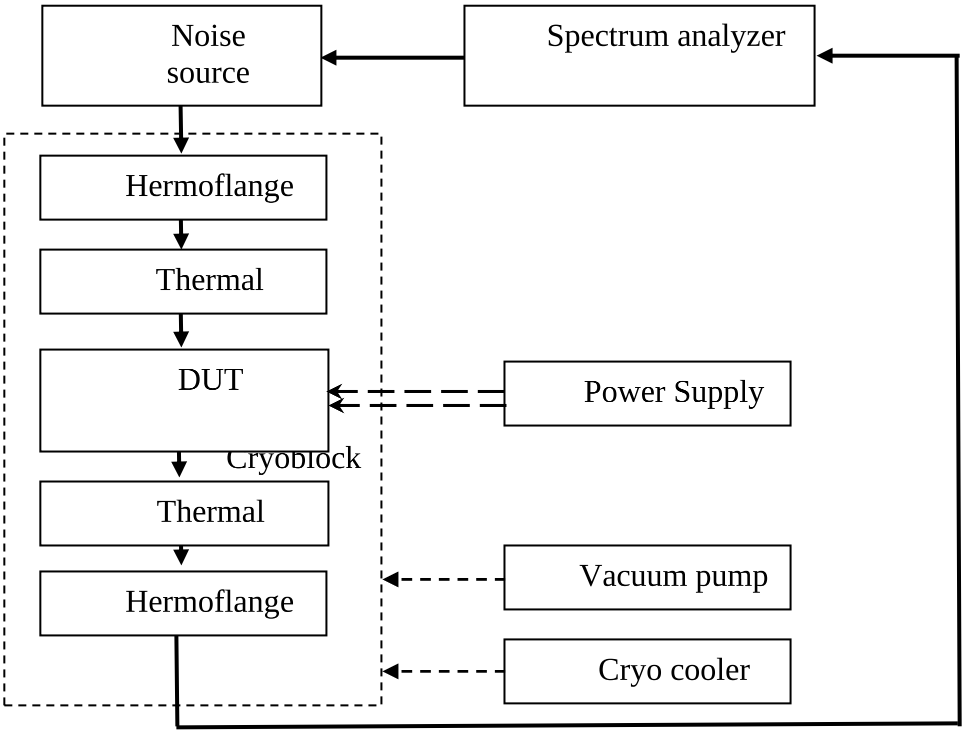

Fig. 2. Block diagram of a cryogenic measuring installation

The measurements were carried out in measuring equipment with ferrite isolators ФПВН-381 installed at the input and output.

At the first stage, to assess the operability of the transistor at cryogenic temperatures, the I–V characteristics of the transistor were measured at various ambient temperatures. The current-voltage characteristic at temperatures from 90 to 300 K is shown in Fig. 3.

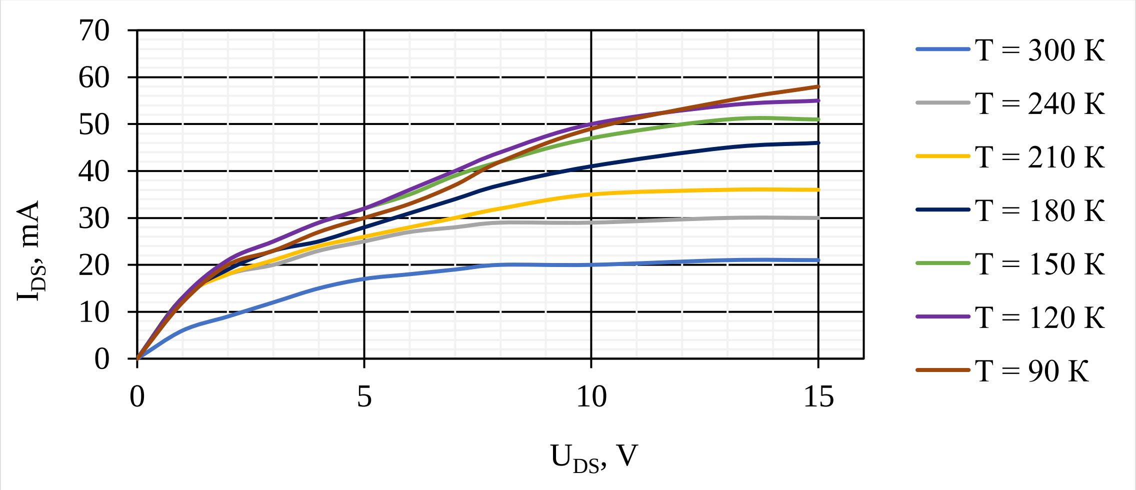

Fig. 3 I–V characteristics of the test transistor in the temperature range

Analysis of the I–V characteristic shows that at low voltage at the drain, the drain current increases slightly with decreasing base temperature, and at high voltages, the change becomes significant and at a drain-source voltage of U_{DS}> 15 V, the drain current I_{DS} increases three times with a temperature difference ΔT = 210 K. This is due to an increase in the mobility of charge carriers in the channel, caused by the deactivation of deep levels with decreasing temperature. At the next stage, the gain and noise figure of the transistor were measured at the drain voltage UDS = 8 V, since at higher voltages a significant increase in current is observed depending on the temperature. In order to ensure the stability of measurements and ensure the constancy of the equivalent impedances of the generator and the load at the terminals of the transistor by external matching networks, matching was made in the band ΔF = 9.0 ... 10, GHz. The measurement results are presented in Fig. 4 and Fig. 5

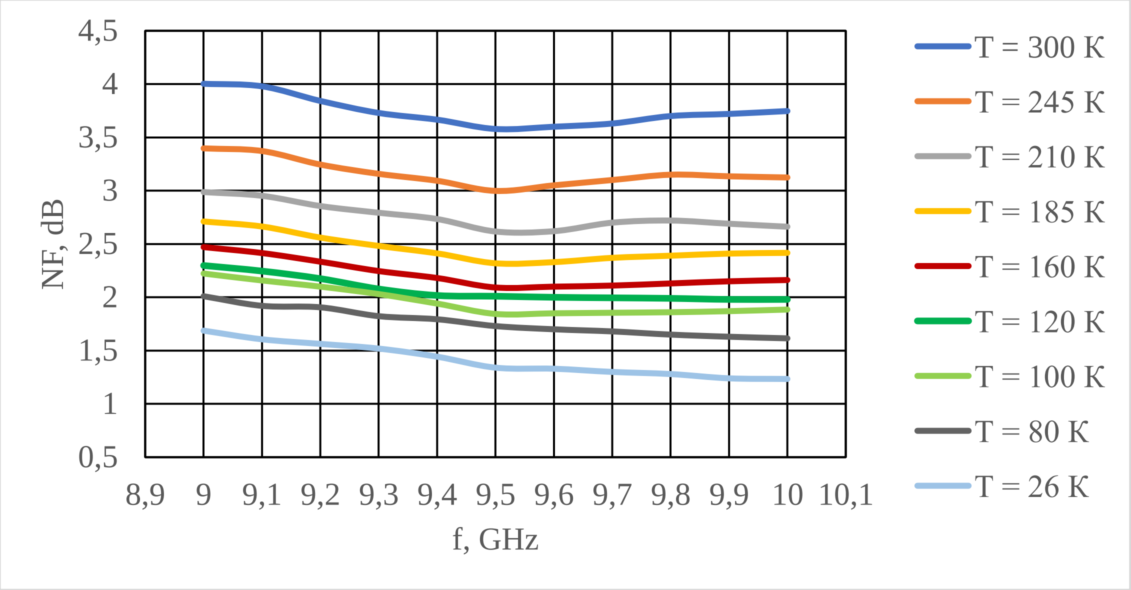

Fig. 4 GaN HEMT measured noise figure

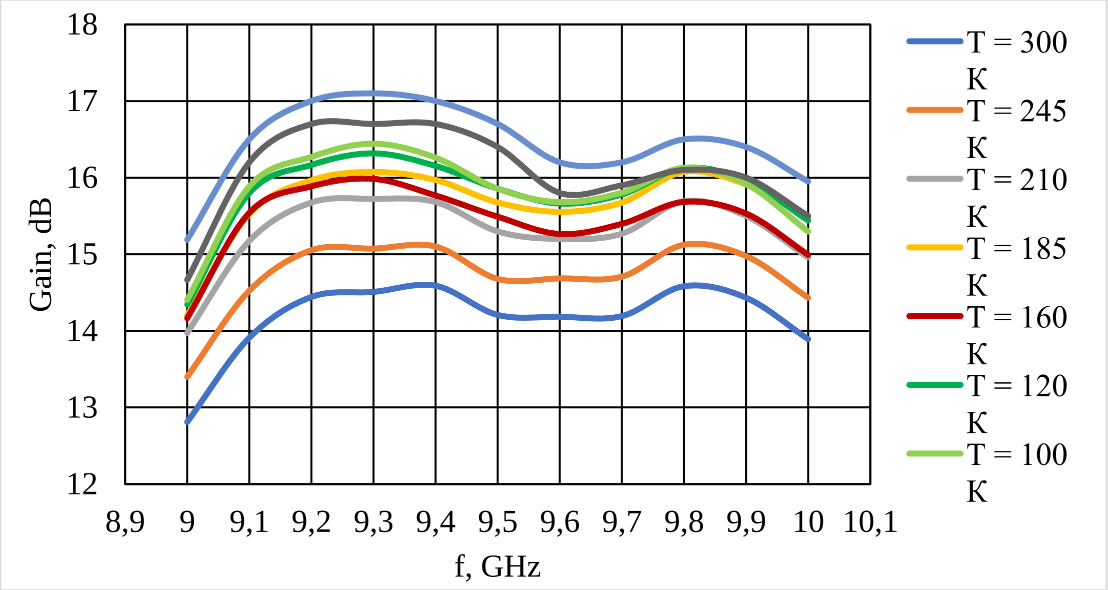

Fig. 5 GaN HEMT measured gain

From the presented dependencies it is seen that with decreasing temperature the gain increases by 3 dB, and the noise figure decreases by 2 dB at a case temperature near to Tc = 26 K. It is important to note that during cooling/heating, there are no failures and self-excitation of the transistor. Consequently, the use of gallium nitride technologies is possible to create an effective highly reliable low-noise cryo-LNA for use both as a part of space-based radio equipment, where large differences in ambient temperature are possible, and as part of ground-based radio astronomy observation and communication stations using cryo-cooling systems to increase the sensitivity of receivers.

Conclusion

It has been established that low-noise GaN HEMTs are stably operable at low temperatures, up to 20 K, while a significant decrease in noise temperature indicates that there is an “idealization” of a two-dimensional electron gas associated with the regularization of the boundaries between the layers of the AlGaN/GaN heterostructure.

The conducted researches confirm the possibility of creating a low-noise nitridagyllium electronic component base with low levels of intrinsic noise and stability of parameters for use in cryogenic temperatures, which ensures its application as a part of receivers of space-based radio-electronic systems and cryo-cooled radio astronomy systems.

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СОВЕРШЕНСТВОВАНИЕ БИЗНЕС-МОДЕЛИ ПАССАЖИРСКОЙ ЖЕЛЕЗНОДОРОЖНОЙ КОМПАНИИ

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IMPROVING THE PASSENGER BUSINESS MODEL RAILWAY COMPANY

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Аннотация

Статья посвящена вопросам совершенствования модели управления в пассажирской железнодорожной компании дальних перевозок. Рассматриваются предпосылки и условия изменения бизнес-модели компании в условиях жесткой конкуренции с другими видами транспорта и выполнения социально-значимой функции. В статье представлены стратегические направления развития компании АО «Федеральная пассажирская компания», дочернего общества ОАО «РЖД».

Annotation

The article is devoted to improving the management model in a long-distance passenger railway company. We consider the prerequisites and conditions for changing the company's business model in the face of fierce competition with other modes of transport and performing a socially significant function. The article presents the strategic directions of development of the company "Federal passenger company" JSC, a subsidiary of JSC "Russian Railways".

Ключевые слова: железнодорожный транспорт, пассажирская компания, стратегия развития, бизнес-модель, структура управления, конкуренция, миссия, видение, АО «ФПК», ОАО «РЖД».

Keywords: railway transport, passenger company, development strategy, business model, management structure, competition, strategy, vision, JSC "FPC", JSC "Russian Railways".

Введение

В современных условиях повышение требований пассажиров к сервису железнодорожной перевозки, развитие скоростного и высокоскоростного движения, а также обострение конкуренции с другими видами