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Numerical simulation of the parameters of an energy-efficient low-noise transistor for use in the amplification path of a miniature radiothermograph

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Abstract. The high current consumption of the amplifying cascades in the miniature case of the radiothermograph with the microcircuits existing today leads to a significant increase in the temperature inside the case with the reference noise source located there and subsequent heating of the surrounding tissues with distortion of the picture of the real field of internal temperatures of the biobject. The existing problem can be solved by creating new active elements of specialized monolithic microwave chips – low-noise transistors, for which the requirements of high energy efficiency, primarily low heat dissipation into the surrounding space, low noise level and sufficient gain will be taken into account when designing heterostructures. The paper presents the results of numerical simulation of a low-noise transistor with low power consumption for use as part of monolithic integrated circuits of an energy-efficient low-noise amplifier for use in the amplifying path of a miniature radiothermograph.

Keywords: medical radiothermograph, MIC microwave, energy consumption, energy efficiency

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Материалы конференции
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Численное моделирование параметров энергоэффективного малошумящего транзистора для применения в усилительном тракте миниатюрного радиотермографа

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Аннотация. Высокое потребление тока усилительных каскадов в миниатюрном корпусе радиотермографа при существующих на сегодня микросхемах приводит к значительному повышению температуры внутри корпуса с находящимся там опорным источником шума и последующему нагреву окружающих тканей с искажением картины реального поля внутренних температур биобъекта. Существующую проблему можно решить созданием новых активных элементов специализированных монолитных СВЧ микросхем – малошумящих транзисторов, для которых уже при проектировании гетероструктур будут учитываться требования высокой энергоэффективности, прежде всего низкого тепловыделения в окружающее пространство, малого уровня шумов и достаточного коэффициента усиления. В работе представлены результаты численного моделирования малошумящего транзистора с низким потреблением мощности для использования в составе монолитных интегральных схем энергоэффективного малошумящего усилителя для применения в усилительном тракте миниатюрного радиотермографа.

Ключевые слова: медицинская радиотермография, МИС СВЧ, энергопотребление, энергоэффективность

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Introduction

The amplifying path of a medical radiothermograph has extremely high requirements for miniaturization, an error in determining body temperature not exceeding tenths of a degree, a record low level of intrinsic noise in the microwave range, etc.

The low level of the received signals of the human body's own radiation leads to the need to provide a gain of the receiving path of about 80 dB with minimal levels of its own noise. The construction of such a path requires several chips with a total current consumption in the operating mode of the order of hundreds of milliamps. Such current consumption of amplifying cascades in a miniature radiothermograph housing, with the efficiency of these microcircuits existing today, leads to a significant increase in temperature inside the housing with a reference noise source located there and subsequent heating of the surrounding tissues with distortion of the picture of the real field of internal temperatures of the biobject. The existing problem can be solved by creating new active elements of specialized monolithic microwave chips – low-noise transistors, for which the requirements of high energy efficiency, primarily low heat dissipation into the surrounding space, low noise level and sufficient gain will be taken into account when designing heterostructures [1].

Materials and Methods

Heterostructures of A3-B5 group semiconductors can reasonably be considered a promising system of materials for solving the above problem. The experience gained by the authors of successful mathematical modeling and practical implementation of heterostructural microwave transistors with high electron mobility [2], suggests a reasonable probability of a successful solution to the above problem of creating a special low-noise microwave transistor with reduced heat dissipation.

If we set ourselves the goal of reducing the current consumption by the active element of such an MIC, while maintaining a high gain, then pay attention to the evaluation of the behavior of charge carriers in the transistor channel with an increase in the locking potential at the gate. Calculations show that the shape of the quantum well is distorted and some of the electrons can move away from the gate and react less strongly to the controlling effects of its electric field.

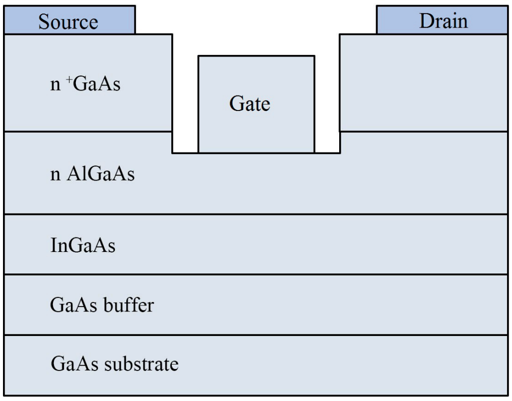

Fig. 1. Schematic cross section of a base transistor with high electron mobility based on gallium arsenide with an indium channel

This leads to the fact that in the area of low currents, the steepness of the transfer characteristic becomes insufficient to maintain a high gain of the base active element of the MIC. A radical way to combat the drop in steepness is the use of modified heterostructures that provide greater localization of electrons in the area of the transistor channel. For example, a schematic representation of energy zones in the heterostructure of the pHEMT AlGaAs/InGaAs/GaAs transistor and the transistor having an additional heterobarrier on the side of the buffer layer – DpHEMT, as shown in Figure 2.

In modern devices, in order to achieve high gain, it is necessary to increase the quiescent current of a low-noise transistor, which leads to an increase in the total current consumption of the MIC, and it is here that the main reserve for improving the efficiency of the low-noise transistor, as a basic element of the chip, as part of the microwave MIC, without changing its

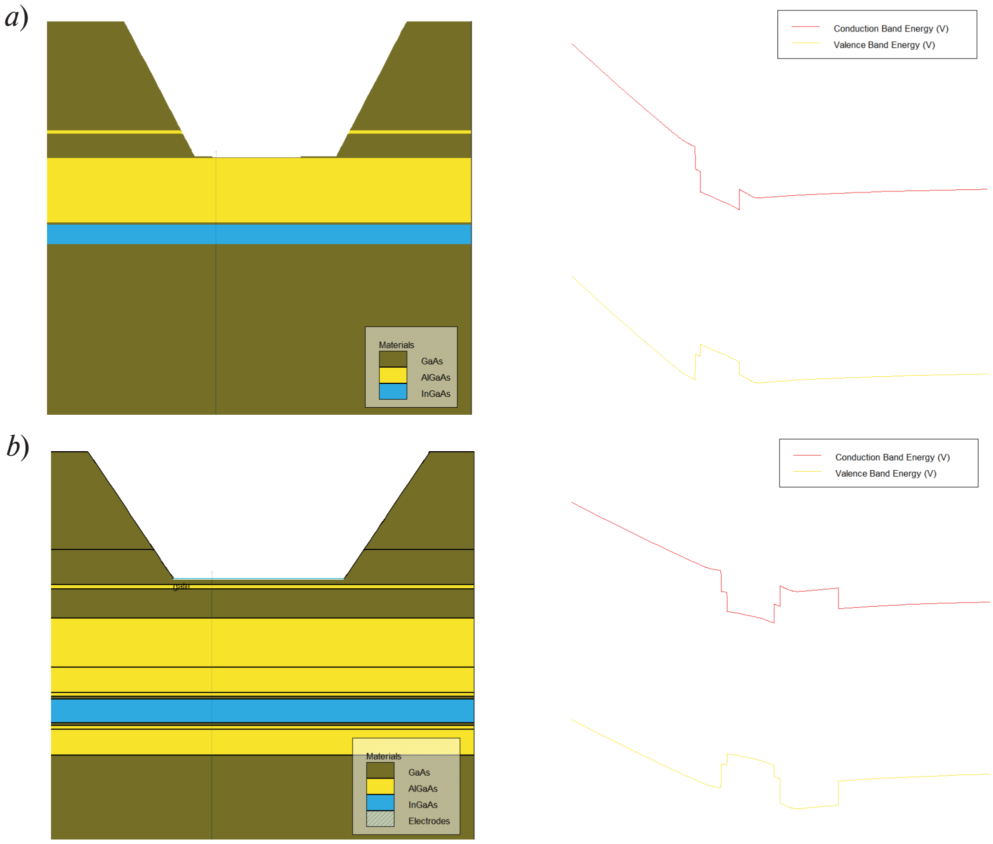

Fig. 2. Schematic representation of energy zones in the heterostructure of pHEMT AlGaAs/InGaAs/GaAs (*a*) and DpHEMT AlGaAs/InGaAs/AlGaAs/GaAs (*b*)

schematic diagram, can be concentrated. Indeed, the presence of a second heterobarrier can significantly reduce the displacement of charge carriers into the buffer layer. This is especially important in the field of low currents, which significantly distinguishes our case of a low-noise device from the known problems of high-power transistors with a double heterobarrier operating in high channel current density modes. In addition, an essential issue remains unexplored for the use of such transistors as part of the microcircuits of low-noise amplifiers. How does the change in the design of the heterostructure affect the noise characteristics of the proposed transistor? In the framework of this work, using numerical modeling methods, we evaluated the effect of the proposed changes in the heterostructure on the main static characteristics and noise coefficient of the proposed transistor [3].

Results and Discussion

Since the element component base implemented on AlGaAs/GaAs pHEMT heterostructures has the lowest noise coefficients, it is these heterostructures that are used in the manufacture of hybrid and monolithic low-noise amplifiers (LNA). In this work, the parameters of a heterostructural transistor for the MIC amplification path of a medical radiothermograph were optimized. As a result of optimizing the transistor design based on the previously specified requirements, a calculated steepness characteristic was obtained, clearly showing the increased amplifying properties of the proposed transistor in the low current region, which directly leads to the possibility of a significant reduction in current consumption of the entire chip. The noise characteristics of the transistor were also simulated before and after the optimization of the device design. The analysis of noise characteristics in our work is based on the representation of noise in the form of microscopic local noise sources - microscopic noise source (MNS). When modeling, it is assumed that the statistical behavior of noise at one point of the device is independent of the behavior of noise sinks at all other points of the structure [4–7]. A local noise source is the effect that a microscopic noise source has on the overall noise characteristics of a device. The numerical tool we use has models for three types of microscopic noise sources – diffusion noise, generation-recombination noise and flicker noise. At the same time, the current sources are small and randomly distributed. Then the description of the noise depends on the statistical properties of these microscopic current sources.

The mathematical model describing the distribution of electrons in semiconductor structures is based on a system of Schrodinger and Poisson equations. The diffusion-drift model in TCAD Sentaurus is a standard model based on the diffusion and drift approximation for the equations of semiconductor devices related to the Boltzmann transport equation. In this model, the flow of carriers in the device is caused by both drift and diffusion in the presence of a transverse or longitudinal electric field, as well as generation and recombination of charge carriers. TCAD software numerically solves the Poisson equation and the continuity equation using a self-consistent approach to determine the concentrations of electrons and holes, as well as the electrostatic potential in the grid nodes defined in the structure of the device. In this case, the

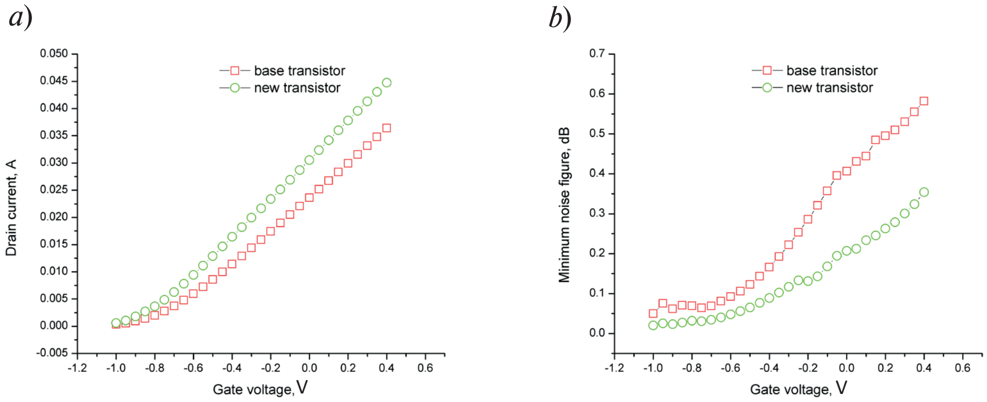

Fig. 3. Calculated characteristics of a transistor of conventional and improved design. The transfer characteristics of the transistors (*a*) and the corresponding characteristics of the minimum noise coefficient (*b*). Squares (red lines) – the usual design, circles (green ones) – the proposed design

constant temperature achieved by the equilibrium between the carrier temperature and the lattice temperature is taken into account, as well as stationary conditions and complete ionization of the introduced impurities are established.

Fig. 3 shows the main results of modeling the transfer characteristics of a conventional and proposed transistor, as well as their corresponding graphs of noise characteristics at the same gate offsets.

Conclusion

The presented numerical simulation results allow us to judge the possibility of significantly reducing the current consumption of the entire amplifier chip and improving its noise characteristics. The results of the work have shown that the optimized transistor design has an even lower noise coefficient compared to the basic one, with the same amplifying properties and lower power consumption, which confirms the correctness of the chosen direction of optimizing the design of the base transistor for microwave MIC (MMIC) low-power LNA.

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