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Study of increasing the energy efficiency of monolithic integrated circuits of the radiometer receiving path using computer modeling methods

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Abstract. The high current consumption of the amplifying cascades in the miniature case of the radiometric receiver with these microcircuits existing today leads to a significant increase in temperature inside the case and subsequent heating with distortion of the picture of the real field of internal temperatures and soil humidity. The existing problem can be solved by creating new active elements from specialized monolithic microwave chips - low-noise transistors, for which the requirements of high energy efficiency will be taken into account when designing heterostructures. The article presents the results of numerical simulation of a low-noise transistor with low power consumption for use in monolithic integrated circuits of an energy-efficient low-noise amplifier of a miniature radiometer.

Keywords: radiometric receiver, MMIC, HEMT, heterostructure, energy efficiency

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Исследование повышения энергоэффективности монолитных интегральных схем приемного тракта радиометра методами компьютерного моделирования

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Аннотация. Высокое потребление тока усилительными каскадами в миниатюрном корпусе радиометрического приемника с существующими на сегодняшний день этими микросхемами приводит к значительному повышению температуры внутри корпуса и последующему нагреву с искажением картины реального поля внутренних температур и влажности почвы. Существующая проблема может быть решена путем создания новых активных элементов из специализированных монолитных СВЧ-чипов - малошумящих транзисторов, для которых при проектировании гетероструктур будут учтены требования высокой энергоэффективности. В статье представлены результаты численного моделирования малошумящего транзистора с низким энергопотреблением для использования в составе монолитных интегральных схем энергоэффективного малошумящего усилителя миниатюрного радиометра.

Ключевые слова: радиометрический приемник, МИС СВЧ, энергопотребление, энергоэффективность

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Introduction

The amplification path of the radiometric receiver must meet extremely high requirements for miniature size, accuracy in determining soil temperature and moisture, record low levels of intrinsic noise in the microwave range, etc.

The low level of received signals leads to the need to ensure the gain of the receiving path of the order of 80 dB with minimal levels of intrinsic noise. The construction of such a path requires several microcircuits with a total current consumption in the operating mode of the order of hundreds of milliamperes. Such current consumption of the amplifying stages in a miniature radiometer case, when using even the most modern microcircuits, leads to a significant increase in the temperature inside the case and subsequent heating of the radiometer with a distortion of the picture of the real field of temperatures and soil moisture. The existing problem can be solved by creating new active elements - specialized monolithic microwave microcircuits of low-noise transistors, for which the requirements of high energy efficiency will be taken into account already during the design of heterostructures, primarily low heat emission into the surrounding space, low noise level and sufficient gain [1].

Materials and methods

For solving the above-mentioned problem, heterostructures of semiconductors of the A3-B5 group are promising. The experience accumulated by the authors of successful mathematical modeling and practical implementation of heterostructure microwave transistors with high electron mobility [2–5] allows us to speak about the reasonable probability of a successful solution to the above-mentioned problem of creating a special low-noise microwave transistor with reduced heat generation.

One of the most effective ways to significantly improve the energy efficiency of a heterostructured transistor is to perform numerical simulations using calibrated TCAD models. Provided that the behavior of the transistor is adequately displayed in numerical models, it is possible to estimate the degree of influence of changes in the design of a heterostructured transistor on its output parameters without significant financial, time, and other resources. At the first stage of the work, the degree of influence of several parameters on the output characteristics of the device was evaluated. Among these characteristics, the steepness of the transmission characteristic of the device occupies a special place as an indicator of its amplifying properties. At the same time,

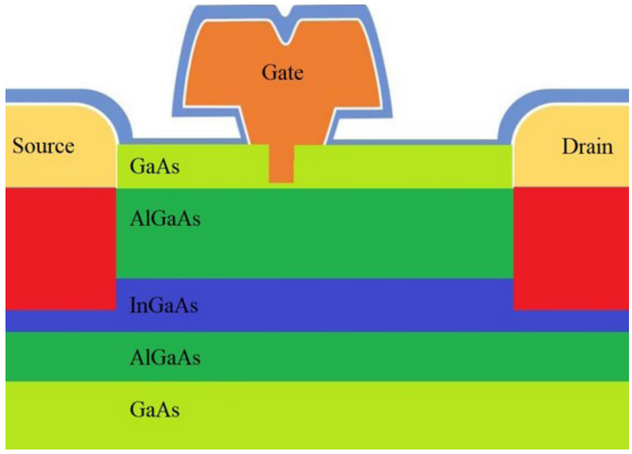

Fig. 1. Schematic view of the heterostructural transistor design

among the parameters of the transistor design, the most obvious for analysis are the depth of the gate in the gate groove, the length of the gate, and the distance between the transistor electrodes and the walls of the gate groove (Fig. 1).

The basic design of the transistor provides a high transconductance only when a sufficiently high drain current is reached. Thus, if it is possible to ensure a high transconductance with a low drain current, then we can expect a significant increase in the energy efficiency of a low-noise amplifier, given the small amplitude of the input signal and the absence of requirements for the output signal power level.

Results and discussion

Thus, to solve this problem, the possibility of increasing the transconductance in the low current region by changing the topology of the transistor was evaluated. An analysis of the results of calculating the transfer characteristic and transconductance for various variants of the transistor topology showed that we can expect a decrease in the quiescent current of the transistor cascades by 20–25%, which is significant, but in some cases insufficient reason to change the design of monolithic integrated circuits in the amplification path of the radiometer.

As a result, minimal changes in the design of the heterostructure can be proposed, which can lead to a significant increase of transconductance in the low current range. Indeed, as can be seen in Fig. 2, the distribution of electrons in the channel of the basic version of the transistor near the locking point is highly heterogeneous in channel thickness.

a) *b*)

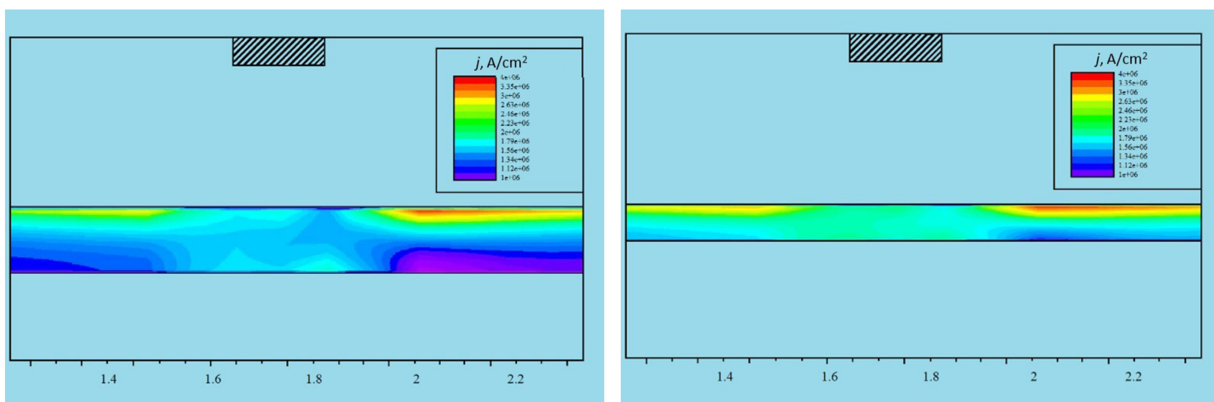

Fig. 2. Distribution of electrons in the gate region and channel of a low-noise transistor: the basic design of the heterostructure (*a*); a new design of the heterostructure with an optimized channel for operation in an energy–efficient mode (*b*)

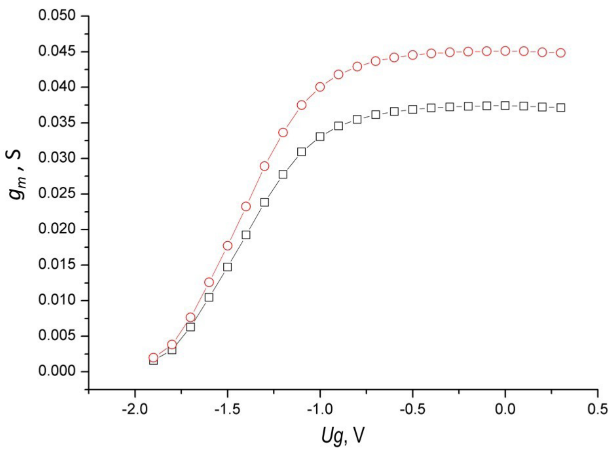

Fig. 3. Calculated transconductance characteristics of a transistor of conventional and new design. Circles (red lines) correspond to the new design thin channel, black lines to the conventional design

This may indicate a decrease in the efficiency of gate field control for current flow in the channel, which leads to a decrease of transconductance in this area of the characteristic. The fact is that for the selected indium content in the InGaAs solid solution, there is the maximum possible channel thickness that can be grown in a pseudomorphic mode. The misalignment of the lattice can be elastically accommodated, usually to a channel thickness of the order of 15–20 nm. It should be noted that the maximum channel thickness is needed to achieve high power of a transistor based on such a heterostructure. In our case, having found a strong heterogeneity in the distribution of charge carriers over the depth of the channel, we can suggest slightly reducing the thickness of the channel, which will increase the uniformity of current flow near the cutoff and, consequently, the controllability of the gate field while maintaining the overall localization of charge carriers in the quantum well. The results of calculations of the transistor heterostructure design are shown in Fig. 2.

As a result, the uniformity of the charge carrier distribution in the channel has significantly improved, which has led to an increase in the efficiency of gate field control and an increase in the transconductance, which is reflected in the calculation results shown in Fig. 3.

Conclusion

The features of the proposed design of the heterostructured field effect transistor directly lead to a significant reduction in the current consumption of the entire microcircuit and to a simplification of its basic circuit. As a result, we were able to achieve a 30% reduction in quiescent current while maintaining a transconductance of more than 350 mS per mm. The practical significance of this work lies in the fact that the developed technique makes it possible to create more energy-efficient amplification stages for radiometric systems. This is especially important for miniature autonomous devices, where low power consumption is a fundamental requirement.

REFERENCES

1. **Gawande R., Bradley R.**, Low-Noise Amplifier at 2.45 GHz, IEEE Microwave Magazine. 11 (1) (2010) 122–126.

2. **Kumar A.S., Dalcanale S., Uren M.J., et al.,** Gallium nitride multichannel devices with latch-induced sub-60-mV-per-decade subthreshold slopes for radiofrequency applications, Nat Electron. (2025).

3. **Tikhomirov V.G., Gudkov A.G., Agasieva S.V., et al.,** Increasing efficiency of GaN HEMT transistors in equipment for radiometry using numerical simulation, Journal of Physics Conference Series. 1410 (2019) 012191.

4. **Tikhomirov V.G., Chizhikov S.V., Gudkov A.G., et al.,** Numerical simulation of the parameters of an energy-efficient low-noise transistor for use in the amplification path of a miniature radiothermograph, St. Petersburg Polytechnic University Journal. Physics and Mathematics. 16 (3.1) (2023) 463–467.

5. **Tikhomirov V., Zemlyakov V., Volkov V., et al.**, Optimization of the parameters of HEMT GaN/AlN/AlGaN heterostructures for microwave transistors using numerical simulation, Semiconductors. 50 (2) (2016) 244–248.

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