Gain Compression of n-MESFET for High Power Applications in MIMO

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Research Article

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Abstract

In this paper, a new n-type recessed Metal semiconductor field effect transistor (MESFET) with GaAs/ SiC materials is designed for high power applications in Multi Input Multi Output (MIMO) systems. Based on electrical characteristics of MESFET, a SPICE model of the proposed device is developed. For power switches, the power MESFETs are used. The feasibility of the technology is validated by the electrical measurements of the device. The operational technology has been shown by the characterizations done on the proposed device. To optimize the electrical performance, the contact resistance technique has to be enhanced. In this work, the output power and Gain compression of proposed n-channel MESFET at 100 MHz and 1 GHz for high input power is obtained. The output power at fundamental frequency of operation for high input power is also obtained.

I. Introduction

In present days, the compound MESFET structures are in high demand because of its use in microwave power applications like power oscillators and power amplifiers. For high power applications, the non-linear behavior of device becomes dominating [1]. Thus a lot of previous research is taken on large signal behavior of MESFET i.e nonlinear behavior. To facilitate the operation of MESFET at high voltage, large energy bandgap is needed [2]. Also high electron velocity of transistor increases the frequency of switching action. To facilitate the device to operate in harsh environments and high temperatures, high melting point and high thermal conductivity are required [3]. Due to variation in channel conditions, for high switching of operations MESFETs are prone to self heating effects. This self heating is due to variation of conditions in channel. The temperature in the channel increases as the current increases inside the channel [4]. This decreases the mobility of carriers inside the channel. When the device is used in places of higher surrounding temperature, the degradation of mobility is still increased [5]. But when the MESFET has either GaAs or SiC material in the channel, these effects are comparatively less when it is compared with commercially available materials like Si or Ge [6]. Hence the MESFETs with GaAs/ SiC materials operate at wide range of temperatures.

Basic logic gates like NAND, NOR, combinational circuits and phase locked loops (PLLs) based on Bipolar junction transistors (BJT), MOSFET are studied by several researchers. The studies are done till high temperatures [7]. However, these advancements mostly concentrated on design of logical blocks and not on integration of power circuits. Primitively dual gate MESFET is designed for power IC's [8]. This is found to be outbreking technology in harsh environments for power applications. The advantage of MESFET over MOSFET is mainly due to poor interface capacity. Also the MESFET technology exhibits good response at high temperature (500° C). The integration of all the devices becomes asset. There is a reduction in number of components and also the economic cost of the system. Also, an improvement of reliability of device is observed. The enhancement effect of charges in MESFETs has found to be same for GaAs MESFET and SiC MESFETs. For instance, when an electron hits the interface of gate-drain then a large signal is observed [9]. The effect of channel modulation occurs at the pinch-off configuration. The effect of charge enhancement depends more on amount of injected charge by striking of electrons.

The best semiconductor material is diamond. This diamond has large band gap (5.5 eV), high breakdown field ($> 10 \text{ MV/cm}$), higher thermal conductivity ($> 3000 \text{ W m}^{-1} \text{ K}^{-1}$), greater electron mobility ($2000 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$). The wider band gap has many advantages but also results in critical issues. These lead to limited ionized dopant concentrations at lower temperature. In this paper, a new n-type recessed MESFET is proposed. The gain compression of wide bandgap MESFETs is studied using GaAs/SiC materials [10]. The output power using GaAs/SiC materials is analyzed for high input power. This paper gives an insight into integrated circuit technology based on planar configuration of MESFET, where gate width can be scaled.

The organization of the paper is as follows: Section II shows the proposed n-MESFET using two different materials. The gain compression and output power of n-MESFET for two different materials is discussed in Section III. The conclusion of the paper is presented in Section IV.

II. Proposed Structure

Figure 1 shows the schematic view of proposed recessed MESFET. The recessed area is shown in Figure 1 under the gate electrode. The 2-dimensional simulations are performed by ATLAS simulator in SILVACO TCAD. To achieve proper results, suitable models are invoked in the simulator. These models include Auger recombination, SRH recombination, CVT models etc

Mercury module is used in this simulation. Epitaxial FETs are modelled using Mercury module. The FETs having stable epitaxial structure and stable doping profile from the source to the drain are called Epitaxial FETs. To remove the circuit that is surrounding the FET, NETWORK CLEAR command is used. To have simulation in large-signal harmonic balance of the FET, Mercury solves the FET within the external circuit. This type of simulation is usually not required when the circuit simulation is having either the DC or small signal behavior. The MODELS n-DEPLETION tells the Mercury simulator that device is n-type depletion. To optimize the simulation, Mercury uses this information [11]. To characterize the channel, the POISSON command is used by Mercury as a function of surface conditions. To calculate the transport mechanisms, Mercury uses 1D simulation [12]. Small number of mesh points are used by Mercury module. Thus, to simulate large signal behavior of FET, Mercury uses harmonic balance method. When compared with the matrices of DC simulation of FET, the matrices are 25-100 times bigger for harmonic balance method. The harmonic balance simulation at 100 MHz and 1 GHz of n-type MESFET is characterized in this paper.

Table I. Device parameters used in device

Description	Value
Gate length	7 nm
Buried oxide thickness	100 nm
Source thickness	50 nm
Drain thickness	50 nm
Source length	75 nm
Drain length	75 nm
Channel region doping	$1 \times 10^{17} \text{ cm}^{-3}$
Source region doping	$1 \times 10^{18} \text{ cm}^{-3}$
Drain region doping	$1 \times 10^{18} \text{ cm}^{-3}$

iii. Results And Discussion

To have the suitability of MESFET for high power applications, proper gate length and width are selected. Table I presents the parameters used in the proposed device. The proposed n-MESFET is formed on 100 nm buried oxide (BOX) layer. This BOX layer provides the support for the MESFET and also used for current transport [13]. The study of Gain compression is studied by using two different materials i.e GaAs and SiC for the proposed n-MESFET. Fig. 2 shows the variation of Gain (in dB) with the input power (in dBm). The gain is maintained constant up to -30 dBm for both the materials. There is no significant change observed. Both the materials show almost negligible impact up to -30 dBm. After -30 dBm there is a linear decrease of gain w.r.t input power. Linear decrease is observed for both the materials and it results in Gain rolloff/compression [14]. As the input power approaches 0 dBm, the SiC MESFET shows faster rolloff than the GaAs MESFET. From the gain compression point of view, the SiC material shows better performance than GaAs MESFET. Fig. 2 demonstrates the gain compression performance of SiC MESFET, GaAs MESFET for high input power.

Figure 3 shows the gain compression of n-MESFET with GaAs/ SiC materials at 1 GHz frequency. At 1 GHz operating frequency, the gain (in dB) is constant up to -20 dBm of input power. Both the materials (GaAs, SiC) show constant gain till -20 dBm. After -20 dBm there is a significant rolloff of gain. The compression ratio of gain is higher for SiC than GaAs. Also the rolloff factor is also higher for SiC.

The output power (in dBm) at 1 GHz plotted against input power (in dBm) is shown in Fig. 4. The output power increases linearly for GaAs MESFET than SiC MESFET. This is mainly due to lower compression ratio of GaAs MESFET. The output power saturates after -15 dBm for both GaAs MESFET and SiC MESFET. Similarly the output power (in dBm) at 100 MHz versus input power (in dBm) is shown in Fig. 5.

The performance of GaAs MESFET and SiC MESFET is unaltered at 100 MHz when compared to their performance at 1 GHz.

Iv. Conclusion

The MESFET devices has shown dominating performance for high power applications especially in MIMO structures. To suit MESFET for high power applications, large bandgap materials are needed. In this paper, two different bandgap materials are taken and the study of MESFET with GaAs and SiC is analyzed for high input power. The output power estimation (in dBm) for two different materials at 1 GHz and 100 MHz is studied. The gain compression ration is high for SiC material than GaAs material. Thus the SiC MESFET is highly suitable for applications of higher power rating and multi input multi output systems.

Declarations

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Author's Contributions

Author (Umamaheshwar Soma) studied, calibrated the results for applications and wrote the paper.

Availability of data

The referred papers will be available on request.

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Conflict of Interest

Authors declare no conflict of Interest.

Ethics Approval

The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

Consent to participate

All authors voluntarily agree to participate in this review paper.

Consent for Publication

References

1. H. Honda, M. Ogata, H. Sawazaki, S. Ono, and M. Arai, "RF characteristics of short-channel SiC MESFETs," *Mater. Sci. Forum*, vol. 433–436, pp. 745–749, 2003.
2. H. Ohyama, K. Takakura, K. Umemura, K. Shigaki, T. Kudou, M. Arai, S. Kuboyama, S. Mastuda, C. Kamezawa, E. Simoen, and C. Claeys, "Radiation-induced defects in SiC-MESFETs after 2-MeV electron irradiation," *Phys. B*, vol. 376–377, pp. 382–384, 2006.
3. . R. Weatherford, D. McMorro, W. R. Curtice, A. R. Knudson, and A. B. Campbell, "Single event induced charge transport modeling of GaAs MESFETs," *IEEE Trans. Nucl. Sci.*, vol. 40, pp. 1867–1871, 1993
4. Aditya, M., Rao, K.S., Sravani, K.G. et al. Simulation and Drain Current Performance analysis of High-K Gate Dielectric FinFET. *Silicon* (2021).
5. M. Nishiguchi, T. Hashinaga, H. Nishizawa, H. Hayashi, N. Okazaki, M. Kitagawa, and T. Fujino, "Radiation tolerant GaAs MESFET with a highly-doped thin active layer grown by OMVPE," *IEEE Trans. Nucl. Sci.*, vol. 37, pp. 2071–2075, 1990.
6. J. S. Laird, H. Toshio, O. Shinobu, and I. Hisayoshi, "High-injection carrier dynamics generated by MeV heavy ions impacting high-speed photodetectors," *J. Appl. Phys.*, vol. 98, p. 013530, 2005.
7. Aditya, M., Rao, K.S. Design and Performance Analysis of Advanced MOSFET Structures. *Trans. Electr. Electron. Mater.* (2021).
8. S. Dutta, "A theoretical study on the temperature-dependent RF performance of a SiC MESFET," *Int. J. Electron.*, vol. 105, no. 7, pp. 1117–1128, Jul. 2018.
9. Aditya, M., Srinivasa Rao, K., Sravani, K., Guha, K. (2021). 'Design, simulation and analysis of high-K gate dielectric FinField effect transistor', *International Journal of Nano Dimension*, 12(3), pp. 305-309. doi: 10.22034/ijnd.2021.681554
10. F. Djeflal and N. Lakhdar, "An improved analog electrical performance of submicron Dual-Material gate (DM) GaAs-MESFETs using multiobjective computation," *J. Comput. Electron.*, vol. 12, no. 1, pp. 29–35, Mar. 2013.
11. H. Lv, Y. Zhang, Y. Zhang, and L.-A. Yang, "Analytic model of IV characteristics of 4H-SiC MESFETs based on multiparameter mobility model," *IEEE Trans. Electron Devices*, vol. 51, no. 7, pp. 1065–1068, Jul. 2004.
12. C. Gaquiere, S. Trassaert, B. Boudart, and Y. Crosnier, "High-power GaN MESFET on sapphire substrate," *IEEE Microw. Guided Wave Lett.*, vol. 10, no. 1, pp. 19–20, Jan. 2000.
13. T. Hirao, S. Onoda, M. Oikawa, T. Satoh, T. Kamiya, and T. Ohshima, "Transient current mapping obtained from silicon photodiodes using focused ion microbeams with several hundreds of MeV," *Nucl. Instr. Meth. B*, vol. 267, pp. 2216–2218, 2009.

14. D. McMorow, A. R. Knudson, J. B. Boos, D. Park, and J. S. Melinger, "Ionization-induced carrier transport in InAlAs/InGaAs high electron mobility transistors," IEEE Trans. Nucl. Sci., vol. 51, pp. 2857–2864, 2004.

Figures

Figure 1

Schematic view of proposed MESFET

Figure 2

Gain compression of n-MESFET for high input power

Figure 3

Gain compression of n-MESFET at 1 GHz

Figure 4

Output power at 1 GHz

Figure 5

Output power at 100 MHz