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Dual gate material (Au and Pt) based double-gate MOSFET for high-speed devices

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Keywords

Double-gate MOSFET; high-speed devices; high-k dielectric; microelectronics; nanotechnology; VLSI.

Abstract

Aluminium Gallium Arsenide (AlGaAs) is a semiconductor material used in the latest design of double heterostructure laser diodes. This semiconductor is mostly available in the arbitrary alloy form between Gallium Arsenide and Aluminium Arsenide. It is derived from the Tri-Methyl-Gallium (TMG/TMGa), and Arsine (AsH3), both the chemicals are pyrophoric and toxic. The resistance is less between source and drain contacts in the case of AlGaAs so that it has been proposed as a material to grow contacts on Indium Phosphide (InP) layer. The AlGaAs uses an ion implantation model for a design purpose which lowers the thermal power while the operation of the device. The parasitic capacitance has to be taken care of while designing a device using this material since the capacitance affects much in the AlGaAs based devices. The average velocity of the electrons has been observed to be increased by 14.63 % in the Au-gate (gate-1) and Pt-gate (gate-2) material-based Double-Gate (DG) MOSFET compared to the Silicon-based DG MOSFET. This paves the way for higher electron mobility, in turn, it can be used in high-frequency device manufacturing. The proposed material can be used in high-speed hybrid applications such as HEMTs and radiofrequency devices for long-haul communication.

Introduction

Gallium Aluminium Arsenide (AlGaAs), a semiconductor material that has electrical properties near the Gallium Arsenide (GaAs). The AlGaAs has a similar lattice constant to the GaAs but has a wider bandgap, making them compatible for designing high-speed devices. Usually, this material available in arbitrary alloy form, which depends on the x value, material stays between the Gallium Arsenide (GaAs) and Aluminium Arsenide (AlAs). The value of x mainly impacts the alloy's bandgap, such as $x < 0.4$ makes the direct bandgap. The GaAs have a bandgap of 1.42 eV and AlAs has a bandgap of 2.16 eV. Hence, Gallium Aluminium Arsenide can be used as a barrier in the Gallium Arsenide bulk [1]. This makes the heterostructures more reliable for high-speed applications. The application areas are semiconductor lasers and optoelectronic devices for long-distance wireless communications [2]. This device has been used to construct Quantum Well Infrared Photo (QWIP) detector because Aluminium Gallium Arsenide has higher stability in a lower power budget than GaAs.

Hill et. al. [2] had presented an enhancement-mode MOSFET which is based on III-V semiconductors with gate and insulator layer with metal and high-k-dielectric respectively with the greater mobility of electrons and improved transconductance. These mobility and device parameters are highly suitable for future design of n-channel CMOS transistors and High Electron Mobility Transistors (HEMTs) based on III-V semiconductor MOSFETs. Sen et. al. [3] had demonstrated a detailed analysis of the parameters of $Al_xGa_{1-x}As$/GaAs junction-less Double-Gate (DG) MOSFET form of sensitive biosensor application modules. Allaei et. al. [4] had proposed an extensive and analytic charge-based model for measuring the Short Channel Effects (SCEs) in Gallium Nitride based MOSFETs. Liu et. al. [5] stated Technology CAD models and their detailed analysis for AlGaAs/InGaAs; AlGaN/GaN, and Silicon-On-Insulator TeraFETs are in good agreement with the obtained current-voltage parametrs and the response to the sub Tera-Hz radiation. Hence, the DG-MOSFETs can be designed using AlGaAs material. This paper has been organized as follows. Section II elaborates the design process and its parametric model. Section III has the result and discussion of the proposed model. Finally, Section IV concludes the work and recommends the future aspects.

Infinitesimal Design Model

Wide research has been in the long run to make MOSFETs with advanced dielectric materials with higher k – Kappa value to reduce the SCEs. The scaling down of device models has been developed with high-k dielectric materials grown on the well between the gate contacts. Previously SiO_2 layer was used as an insulator between gate material and channel [6, 7]. The usage of high k dielectric makes more insights into research in device fabrication [8, 9]. The Gold and Platinum gate material has been used to construct DG MOSFETs as shown in figure 1. The average electron velocity is higher than the previously discussed model in [5]. The material's total length has been fixed to 30 nm from the source and drain along with the entire electronic simulation [8-10]. The material behaves faster than the previous average velocity [5, 11, 12]. The drain current as in equation (1) of the proposed work has been calculated as:

$$I_d = \frac{C_0 \mu_n W}{L} (V_{int} - V_t)^2 \tag{1}$$

where L and W are the length and the width of the gate contact, respectively, V_t and V_{int} are the threshold voltage and the interference voltage at the contacts, respectively, C_0 and μ_n are the capacitance of the channel material and the mobility of the electrons under a minimized radiation field, respectively.

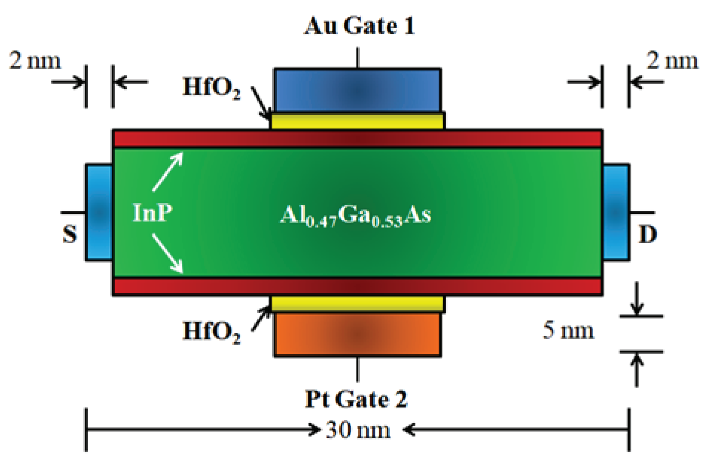

Figure 1. DG MOSFET with Gold and Platinum gate infused with Indium Phosphide as substrate.

Results and discussions

The conduction band profile of the proposed work has been analyzed. The characteristics of the material with dual Au and Pt gate material have been analyzed and comparison is given in figure 2 and figure 3. The mean velocity of electrons along the channel is shown in figure 3. The electrons' velocity has been observed that the Au and Pt behave in compliance with other configurations of materials in the DG MOSFETs design. Schygulla et. al. [8] focuses on the material properties of two III-V semiconductors, AlGaAs and GaInAs, and their usage as middle cell absorber materials in a wafer-bonded III-V/Si triple-junction solar cell.

Table 1. Simulated Analysis of Designed DG MOSFETs.

Ref.	Electrostatic Potential at Drain (V)	Transconductance (S/μm) at Vd = 0.944 V	Transconductance (S/μm) at Vd = 0.167 V
[3]	1.650	2.1141×10^{-4}	4.9643×10^{-3}
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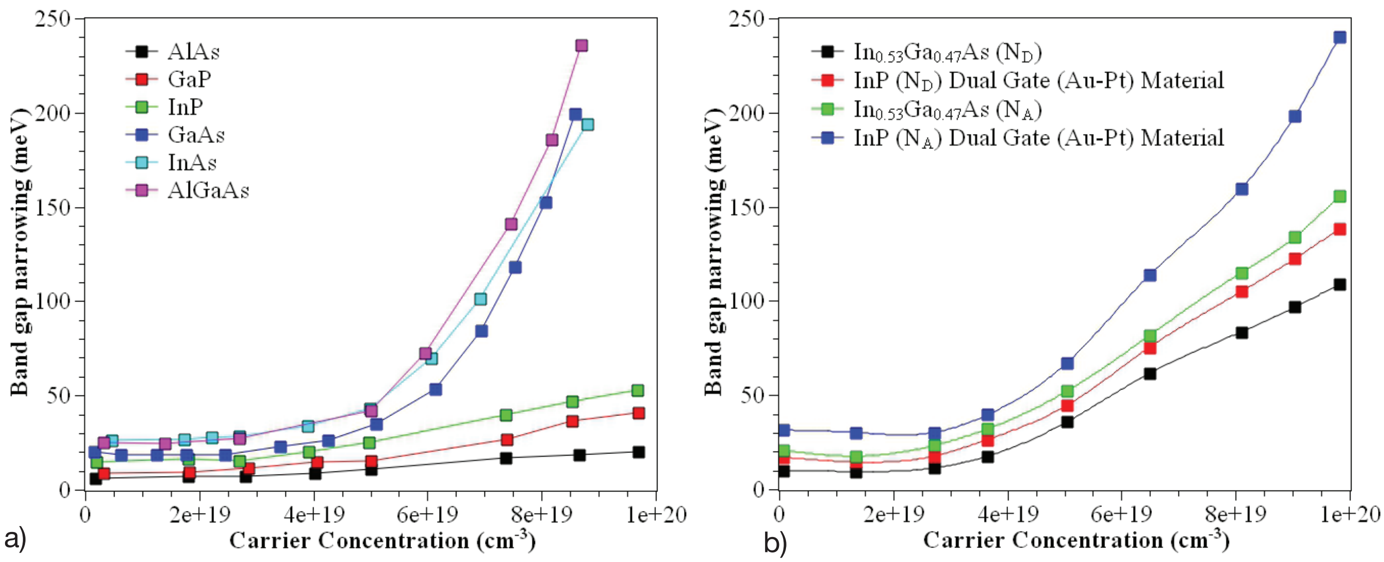

Figure 2. (a) Different Substrate Materials. (b) Dual Gate Material with conventional MOSFET model. Carrier concentration based on dual-gate (Au-Pt) material compared with previous research [1-3, 7].

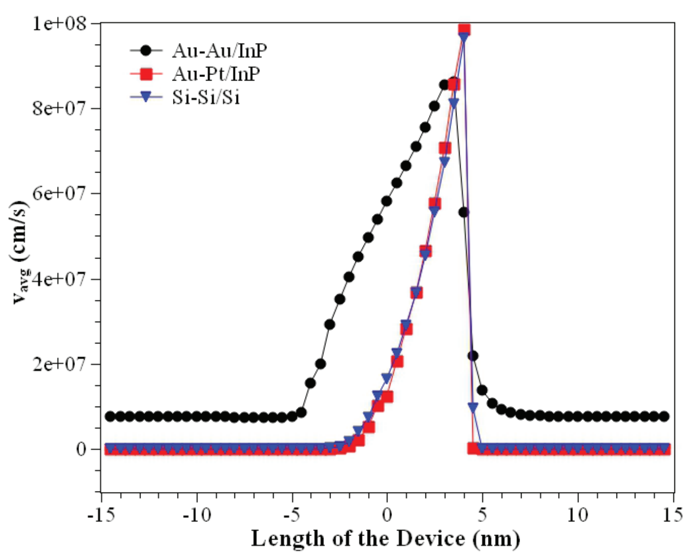

Figure 3. The mean velocity of electrons in the channel for different materials' based devices.

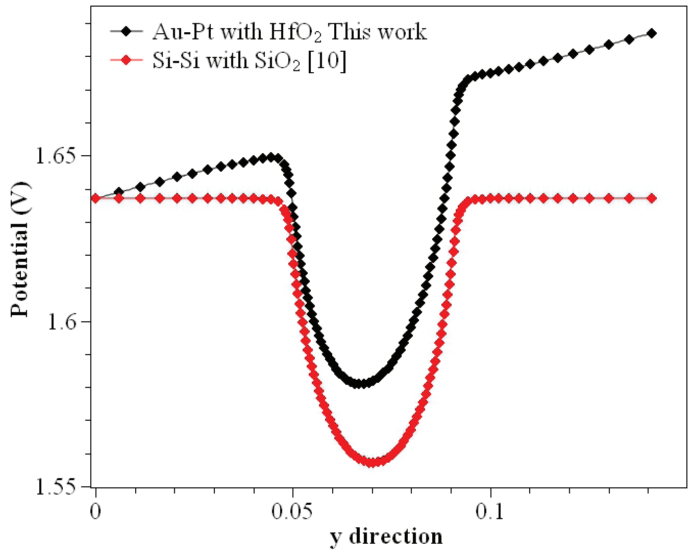

Figure 4. (a) Comparison of electrostatic potential.

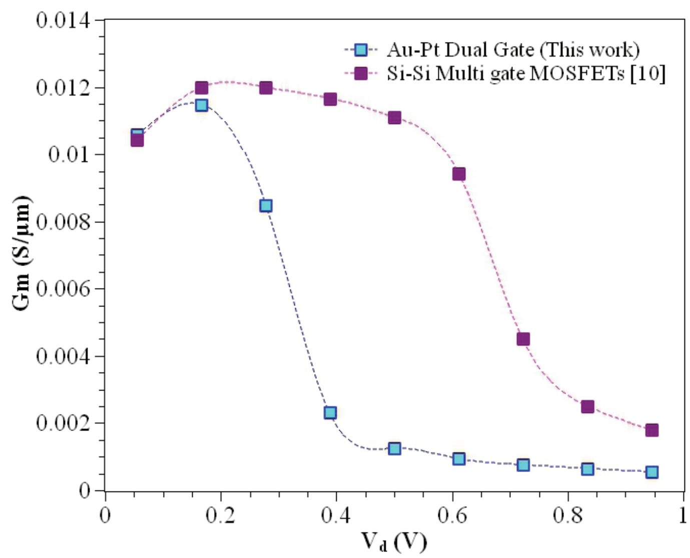

Figure 4. (b) Comparison of Transconductance values with the proposed work and [10].

The detailed analysis has been tabulated in Table I. From this, it can be concluded that the Gold and Platinum dual-gate material-based DG MOSFET provides a deeper and enhanced valley for high-speed operations. The average velocity of the electron in different materials is analyzed, and the results were compared. It describes that the electron velocity is higher in gold and platinum-based DG MOSFETs than in Si-Si based DG MOSFETs [11-13]. The comparisons of electrostatic potential and transconductance parameters have been shown in figure 4.

Conclusions and future aspects

Future nano-CMOS device structures are constructed using non-silicon materials to overcome the existing MOSFETs' basic limitations. Materials such as InGaAs and $Al_xGa_{1-x}As$ come across recent research to create faster MOSFETs with more significant scalability factor. These materials have increased mobility of electrons. The gate had greatly influenced the channel potential. As a result of this, the Cylindrical Surrounding MOSFET model was not able to model accurately. Reducing the channel length by 40% can focus on creating the work in the CSDG paradigm.

This work mainly focuses on creating an illustration that is suitable for fully depleted CSDG MOSFETs. Furthermore, the work can be extended in developing the Cylindrical Surrounding Double-Gate (CSDG) MOSFETs with inert semiconductors materials and various other materials

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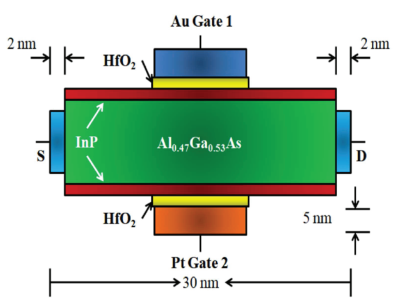

Fig. 1 DG MOSFET with Gold and Platinum gate infused with Indium Phosphide as substrate.

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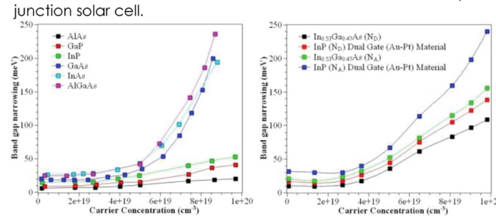
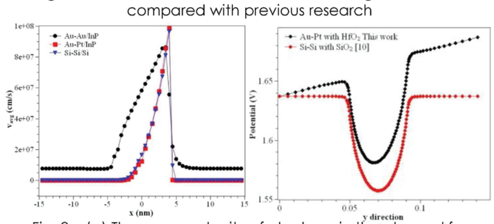


Fig. 2. Carrier concentration based on dual-gate material compared with previous research



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