Comparative Study of Silicon and $In_{0.53}Ga_{0.47}As$-Based Gate-All-Around (GAA) MOSFETs

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1 Introduction

In the modern society, there has been always demand for uninterrupted communication, fast computation, and high-quality entertainment with smaller electronic gadgets. MOSFETs are the backbone of these gadgets. Shrinking dimensions of MOS help to incorporate more features in a single chip, but at the same time due to shrinking in MOS dimensions the phenomena of short channel effects (SCEs) such as subthreshold characteristic, reduction in carrier's mobility, and gate tunneling currents come in the picture. However, the SCEs can be decimated through modification in MOS design.

Multigate devices [1–6] designs like FinFET, Omega FET, and gate-all-around (GAA) are analyzed over different parameters. The GAA MOSFET [6, 7] is becoming a cornerstone due to multidirectional electrostatic control over the gate, superior SCE immunity, and high packing density. In smaller-scaled devices, if the voltage at the drain is expanded, the potential barrier in the channel minimizes, which indicates that the gate loses its control over the channel, overseeing drain-induced barrier lowering (DIBL). This impact is due to the potential distribution from the source/drain region. However, GAA suffers from the low drive current [8]. To overcome the low drive current, the high mobility material $In_{0.53}Ga_{0.47}As$ is used to fabricate the GAA [9], which enhances the working speed at a reduced supply voltage. $In_{0.53}Ga_{0.47}As$-based

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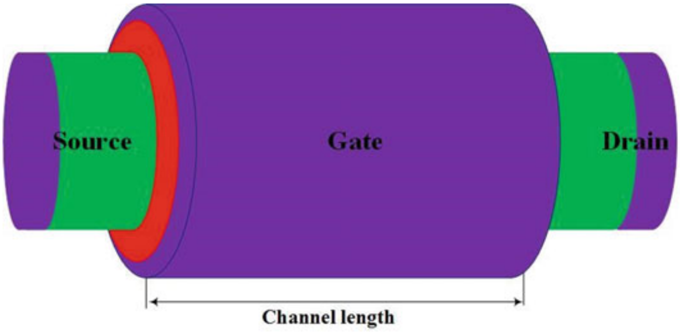

Fig. 1 3D schematics structure design of $In_{0.53}Ga_{0.47}As$-GAA MOSFET

gate GAA MOSFET provides a boost in drive current, excellent immunity to SCEs, enhanced gate-channel electrostatic, and high carrier mobility [10, 11]. Various materials appeared into consideration, among which indium–gallium–arsenide (InGaAs) is one of the considerably focused materials. In conclusion to the works mentioned above, it can be summarized that with reducing dimensions, $In_{0.53}Ga_{0.47}As$-GAA MOS is a fruitful solution for superior computational speed.

In this work, the performance of Si-GAA and $In_{0.53}Ga_{0.47}As$-GAA has been compared. Comparison of Si-GAA and $In_{0.53}Ga_{0.47}As$-GAA devices has been made in terms of variation in OFF-state current (I_{OFF}), ON–OFF-current ratio (I_{ON}/I_{OFF}), subthreshold swing (SS), drain-induced barrier lowering (DIBL), trans-conductance (g_m), and trans-conductance generation factor (TGF) characteristics on ATLAS, a three-dimensional (3D) device simulator from SILVACO.

2 Device Structure and Simulation Approach

The 3D schematics structure of $In_{0.53}Ga_{0.47}As$-GAA MOSFET for simulation is shown in Fig. 1. The cross-sectional view of $In_{0.53}Ga_{0.47}As$-GAA MOSFET is shown in Fig. 2. A thin Al_2O_3 oxide layer wraps over the nanowire channel region. Table 1 shows the device parameters used for simulation. The following models of 3D ATLAS device simulator from SILVACO have been included to perform the simulation of the proposed $In_{0.53}Ga_{0.47}As$-GAA device and Si-GAA devices [12], like drift diffusion charge transport model, Lombardi (CVT) model, concentration-dependent mobility model, and Shockley–Real–Hall (SRH) model.

3 Results and Discussion

Figure 3 presents the potential of $In_{0.53}Ga_{0.47}As$-GAA MOSFET at $V_{GS} = 0$ V and

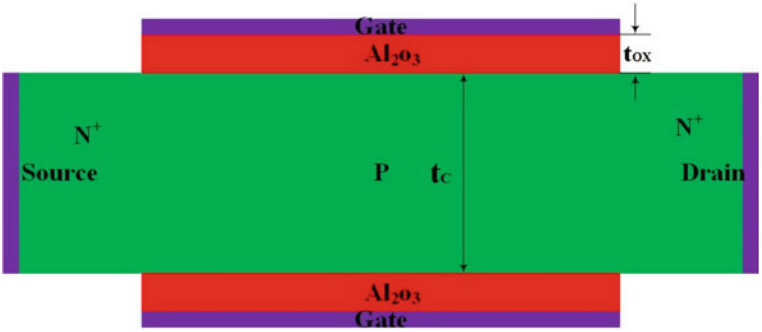

Fig. 2. 2D cross-sectional view of $In_{0.53}Ga_{0.47}As$-GAA MOSFET

Table 1 Silicon and $In_{0.53}Ga_{0.47}As$-based device parameters used for GAA MOSFETs simulation

Parameters	Si-GAA	$In_{0.53}Ga_{0.47}As$-GAA
Channel length (L_C) (nm)	20	20
Source/drain doping (N_D) (cm^{-3})	10^{20}	10^{20}
Channel doping (N_A) (cm^{-3})	10^{15}	10^{15}
Oxide thickness (t_{ox}) (nm)	1	1
Channel thickness (t_C) (nm)	10	10
Metal work-function (ϕ_M) (eV)	4.6	5.1

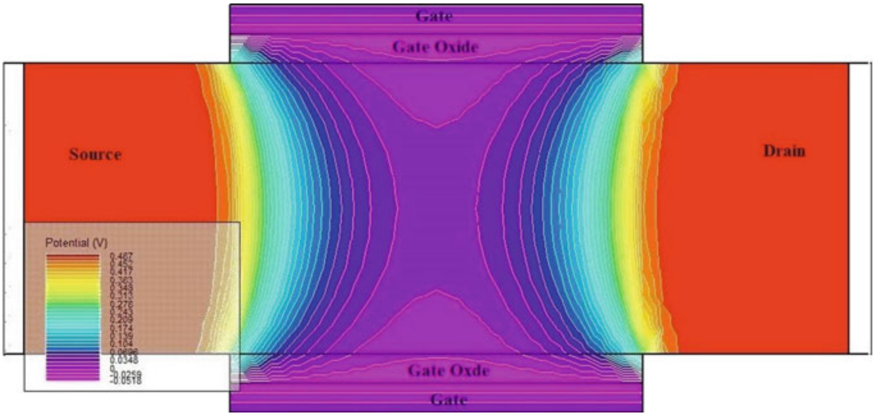

Fig. 3 The cross-sectional contour plot of potential for $In_{0.53}Ga_{0.47}As$-GAA MOSFET at $V_{GS} = V_{DS} = 0$ V

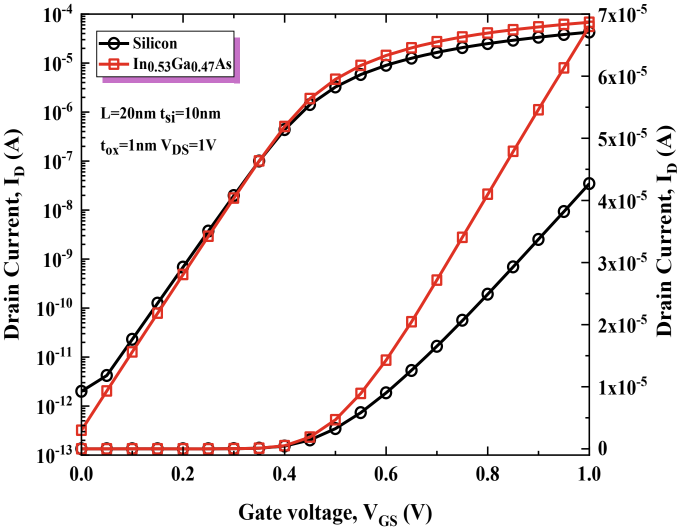

Fig. 4 Variation of drain current (I_D) of Si-GAA and $In_{0.53}Ga_{0.47}As$-GAA MOSFET versus V_{GS} at $V_{DS} = 1$ V

$V_{DS} = 0$ V. The plot indicates the lowest central surface potential, and it demonstrates the gate controllability over the channel region. Figure 4 shows the comparison of drain current (ID) of $In_{0.53}Ga_{0.47}As$-GAA and Si-GAA MOSFET as a function of gate-to-source voltage (V_{GS}) at a drain-to-source voltage (V_{DS}) = 1 V. The improvement of I_{ON} and I_{OFF} is analyzed in $In_{0.53}Ga_{0.47}As$-GAA MOSFET, as shown in Fig. 4. The ON-current is enhanced by 59.62%, but the OFF-current reduces by 84% of $In_{0.53}Ga_{0.47}As$-GAA MOSFET compared to Si-GAA MOSFET. It has occurred due to the high mobility material $In_{0.53}Ga_{0.47}As$ of the device channel with high gate oxide Al_2O_3. Hence, the $In_{0.53}Ga_{0.47}As$-GAA MOSFET is more satisfactory for high-speed switching applications and also low power consumption.

Figure 5 shows the comparison of drain current of $In_{0.53}Ga_{0.47}As$-GAA and Si-GAA MOSFET with V_{DS} at $V_{GS} = 1$ V. The improvement of drain current in $In_{0.53}Ga_{0.47}As$-GAA MOSFET from characteristics of the InGaAs is because the $In_{0.53}Ga_{0.47}As$ has higher mobility than silicon. The comparison between trans-conductance (g_m) of $In_{0.53}Ga_{0.47}As$-GAA and Si-GAA MOSFET against V_{GS} at $V_{DS} = 1$ V is illustrated in Fig. 6. The g_m is a crucial factor for analog and RF applications, and it is moreover essential to define an optimum bias point. For any device, the cut-off frequency is the peak at an optimum bias point. The graph displays that the $In_{0.53}Ga_{0.47}As$-GAA device discloses 53.33% more distinguished g_m than the Si-GAA MOSFET.

Figure 7 illustrates the comparison of TGF (g_m/I_D) of $In_{0.53}Ga_{0.47}As$-GAA and Si-GAA MOSFET against V_{GS} at $V_{DS} = 1$ V. The measurement of g_m and I_D is recognized as the trans-conductance generation factor (TGF). The highest TGF value is near the ideal amount of subthreshold swing 60 mV/decade. In the subthreshold

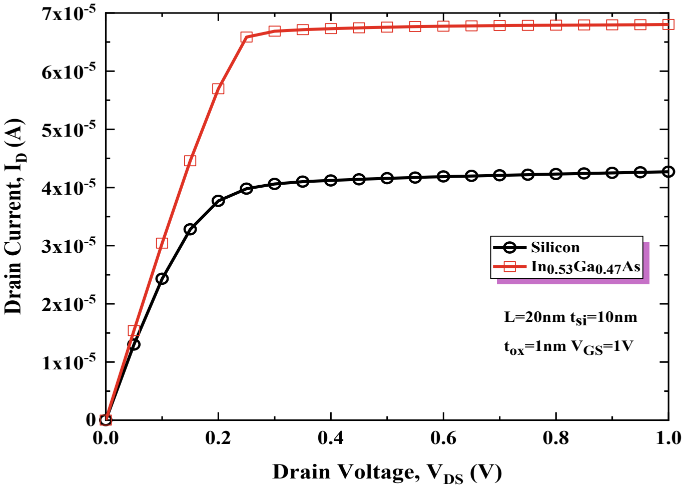

Fig. 5 Variation of drain current of Si-GAA and $In_{0.53}Ga_{0.47}As$-GAA MOSFET versus V_{DS} at $V_{GS} = 1$ V

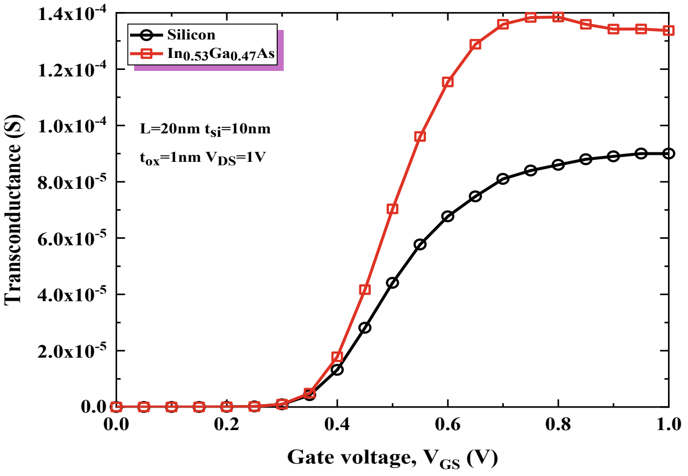

Fig. 6 Variation of trans-conductance (g_m) of Si-GAA and $In_{0.53}Ga_{0.47}As$-GAA MOSFET versus V_{GS} at $V_{DS} = 1$ V

region, TGF is vital for $In_{0.53}Ga_{0.47}As$-GAA MOSFET than the Si-GAA device. The more profitable value of TGF confirms the stable performance of the analog circuit even for low power supply.

Table 2 indicates the analog FOMs of Si-GAA and $In_{0.53}Ga_{0.47}As$-GAA MOSFET

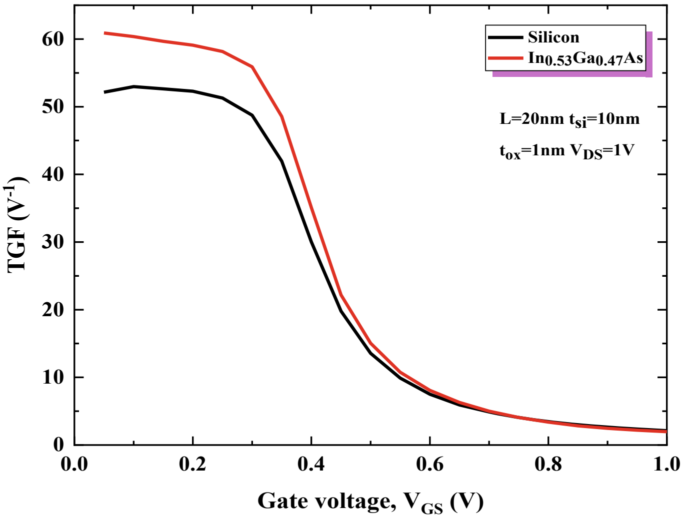

Fig. 7 Variation of TGF (g_m/I_D) of Si-GAA and $In_{0.53}Ga_{0.47}As$-GAA MOSFET versus V_{GS} at $V_{DS} = 1$ V

Table 2 Analog FOMs of Si-GAA and $In_{0.53}Ga_{0.47}As$-GAA MOSFET at $V_{DS} = 1.0$ at a constant threshold voltage

Parameters	Si-GAA	$In_{0.53}Ga_{0.47}As$-GAA
I_{ON} (A)	4.26×10^{-05}	6.80×10^{-05}
I_{OFF} (A)	2.0×10^{-12}	3.2×10^{-13}
I_{ON}/I_{OFF}	$2.13 \times 10^{+07}$	$2.1 \times 10^{+08}$
SS (mV/decade)	67.61	62.49
DIBL (mV/V)	18.47	6.06
g_m (S)	9.0×10^{-05}	1.38×10^{-04}
g_m/I_D	52.13	60.90

at $V_{DS} = 1.0$ at a constant threshold voltage. Table 2 shows that the $In_{0.53}Ga_{0.47}As$-GAA device is organized adequately for analog/RF performance compared to Si-GAA MOSFET. The ON-current ~ 59.62%, g_m ~ 53.33%, and TGF ~ 16.12% of $In_{0.53}Ga_{0.47}As$-GAA devices are higher than the Si-GAA device. However, the $In_{0.53}Ga_{0.47}As$-GAA MOSFET performance parameters such as OFF-current (I_{OFF}) with ~ 84%, subthreshold swing (SS) ~ 8.19%, and DIBL are decreased compared to Si-GAA MOSFET.

4 Conclusion

In this paper, the performance investigation of $In_{0.53}Ga_{0.47}As$-GAA MOSFET has been carried out and compared with the Si-GAA MOSFET for same parameters. Both devices are simulated using a 3D ATLAS TCAD device simulator from SILVACO. The $In_{0.53}Ga_{0.47}As$-GAA MOSFET has revealed much upgraded performance compared to Si-GAA MOSFET. The $In_{0.53}Ga_{0.47}As$-GAA MOSFET has presented superior SCEs immunity compared to Si-GAA. The higher value for ON-current (I_{ON}), g_m, and TGF of $In_{0.53}Ga_{0.47}As$-GAA device has been obtained as compared to the Si-GAA device. However, the $In_{0.53}Ga_{0.47}As$-GAA MOSFET performance factors such as OFF-current, subthreshold swing, and DIBL have been found to diminish compared to Si-GAA MOSFET. The $In_{0.53}Ga_{0.47}As$-GAA MOSFET can be considered to offer excellent analog performance compared to the Si-GAA device. Therefore, it is more superior for high-speed analog and switching applications.

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