Investigation of FinFET as a Temperature Nano-Sensor Based on Channel Semiconductor Type

IOP Conf. Series: Materials Science and Engineering **226** (2017) 012123 doi:10.1088/1757-899X/226/1/012123

Investigation of FinFET as a Temperature Nano-Sensor Based on Channel Semiconductor Type

Yasir Hashim

Faculty of Engineering Technology, University Malaysia Pahang (UMP), Lebuhraya Tun Razak, 26300, Pahang, Malaysia

Corresponding author: yasirhashim@ump.edu.my

Abstract. This paper represents the temperature effect on FinFET transistor and the possibility of using it as a temperature nano-sensor. The MuGFET simulation tool was used to investigate temperature characteristics of the FinFET. Current-voltage characteristics with different values of temperature were simulated. MOS diode connection suggested using the FinFET transistor as a temperature nano-sensor. The final results shows that the best FinFET used as a nano-sensor is with GaAs because it has the greatest ΔI (=10.9%) referring to ΔI at 25ºC, and the best FinFET stable with increasing working temperature is Si-FinFET because it has the lowest ΔI (=6%) referring to ΔI at 25ºC.

1. Introduction

As the Metal Oxide Semiconductor Field Effect Transistor (MOSFET) approaches its down-scaling limits, many new FET structures are being extensively explored. One of these FETs was the FinFET, this transistor structure has attracted broad attention from researchers in academic and semiconductor industry fields [1]-[3].

In general, the embedded electronics applications (that is, for use within equipment) are the best example for using the semiconductor temperature sensor [4]. The transistor based temperature sensors are designed depending on the temperature characteristics of current-voltage curves of the transistor [5-8]. The bipolar transistor can be used as a temperature sensor by connecting the base and collector together, this will use a transistor in diode mode. While the transistor in MOSFET structures can be used as a temperature sensor by connecting the gate with either source or drain.

Electronic devices in nano dimension like diodes, transistors, capacitors and resistors attracting significant attention from the electronics industry due to the drive for ever-smaller electronic circuits. The performance of these new devices, with a wide array of additional applications, will depend on the characteristics of these devices in nano-dimensions. A new more powerful computer chips generation with ultra-small transistors could be more reliable in the future after more discoveries by researchers for these tiny structures. The fabrication of Field Effect Transistors in nano dimensions with new structures is still a technology under development that requires further innovations before challenging state-of-the-art MOSFETs.

The simulation of electronics devices is becoming increasingly important to understand device physics in depth, simulation tools will be used in this research to assess the performance limits of FinFET structure. Experimental work could be supported by simulation tools to accelerate the development of FETs in nano dimensions [9]. Using simulation tools could also identify their strengths and weaknesses, reduce devices cost, , and demonstrate their scalability down to the nm-range [10-11].

2. Results and discussion

The effects of temperature on nanowire transistor's I-V characteristics will investigate using the simulation tool (MuGFET). The MuGFET [12] simulation tool developed and designed at US-Purdue University. The MuGFETsimulation tool was designed for FET structure in nano dimensions. Researchers that use this simulation tool (MuGFET) can choose either PADRE or PROPHET simulators and both simulators are developed in Bell Laboratories. PROPHET is a partial differential equation solver for 1, 2, or 3 dimensions. PADRE is a device-oriented simulator for 2D or 3D device with arbitrary geometry [12]. This software provides many useful characteristic curves for FETs for engineers and deep understanding of physics. The MuGFET simulation tool also provides self-consistent solutions to the Poisson and drift-diffusion equation [12]. MuGFET is used to simulate ballistic transport in the calculation of the characteristics for FinFET (Figure 1) [13].

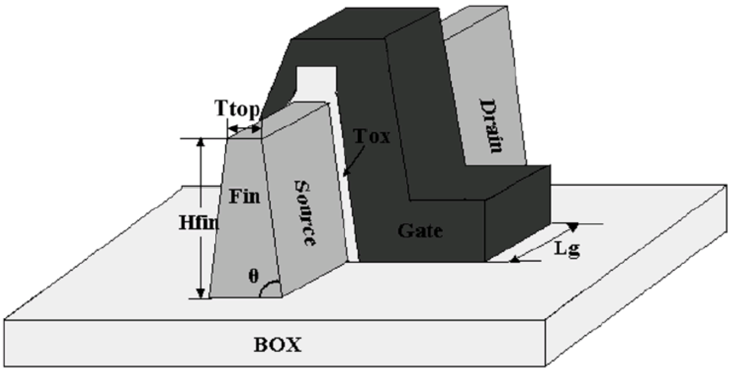

Figure 1. FinFET structure [14].

At the first, the I_d-V_g characteristics of FinFET at temperature (-25, 0, 25, 50, 75, 100, and 125ºC)were simulated with parameters: Channel width =30nm, Channel concentration (P-type) = 10^{16} cm^{-3}, Source length= Drain length=50nm, Source and Drain concentration (N-type) = 10^{19} cm^{-3}, channel length= 45nm and Oxide thickness=2.5nm. The gate leakage current for a FinFET transistor with these dimensions has no effect on the drain current [14]. Temperature effects on the transfer (I_d-V_g) characteristics of FinFET with Si, Ge, GaAs and InAs as a semiconductor illustrated in “Figure 2” at Vd=1V with different values of temperature (-25, 0, 25, 50, 75, 100, and 125ºC) for all types of channel. It can be noted that the higher current happens to InAs channel and the lowest with Si.
The higher the variation in current with increasing temperature happens in higher Vd, so it is possible connecting FinFET as in Figure 3 to test temperature sensitivity and using FinFET as a nano-sensor. Figure 4 shows I_d-T characteristics at V_d=1V with different values of temperature (-25, 0, 25, 50, 75, 100, and 125ºC) for all types of channel. It can be noted that the higher current happens with InAs channel and the lowest with Si.

Figure 5 shows the current change (ΔI) with Temperature characteristics at Vd=Vg=1V for FinFET with different semiconductor channel type, the current change (ΔI) decreases with increasing temperature for all channel types but with InAs the ΔI drop strongly. Figure 6 illustrates the normalized (ΔI) [to ΔI at 25ºC] with temperature characteristics at Vd=Vg=1V for FinFET with different semiconductor channel type. This characteristic shows that the best FinFET used as a nano-sensor is with GaAs because it has the greatest (ΔI) referring to ΔI at 25ºC, and the best FinFET stable with increasing working temperature is Si-FinFET because it has the lowest (ΔI) referring to ΔI at 25ºC.

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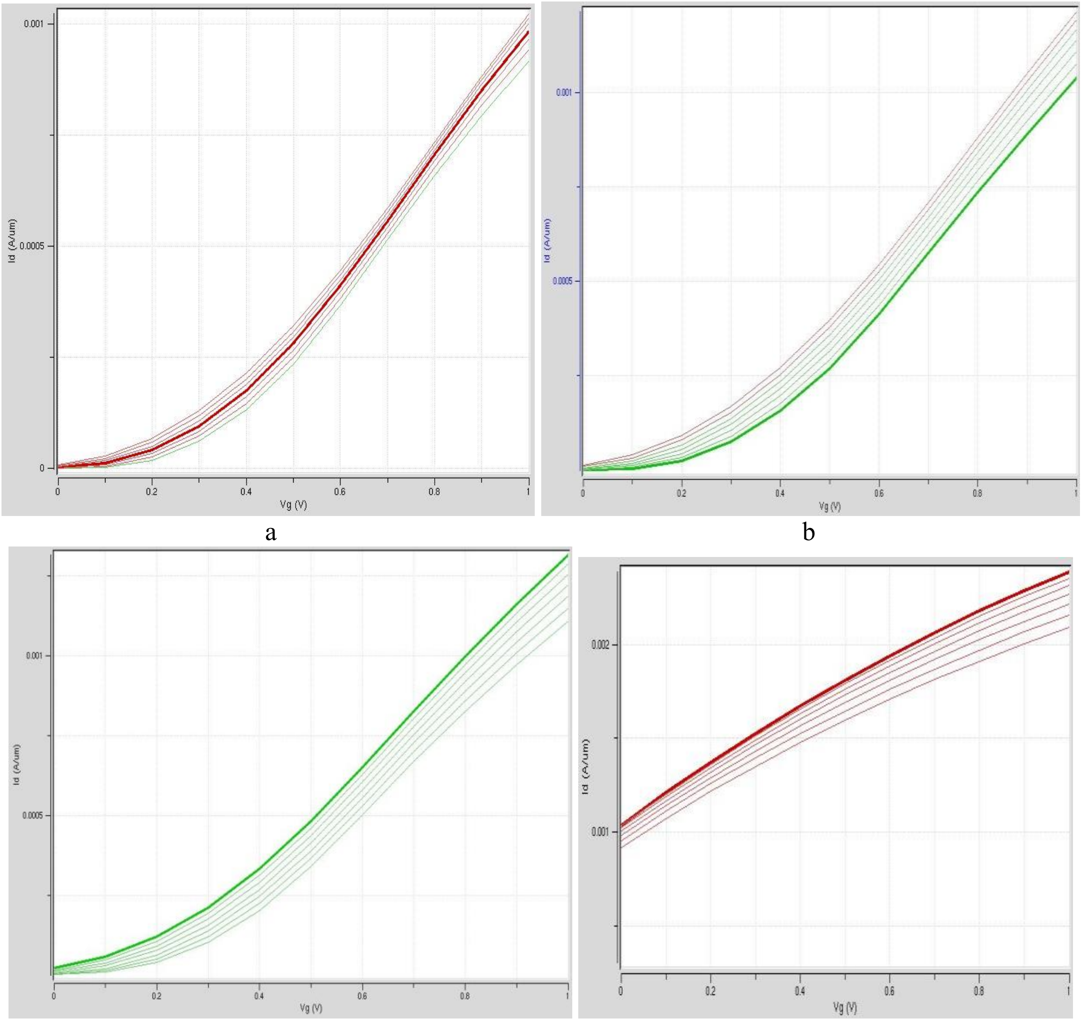

Figure 2. The transfer characteristics (Id-Vg) of (a) Si-FinFET, (b) Ge-FinFET, (c) GaAs-FinFET, and (d) InAs-FinFET at V_d=1V with temperature of (-25, 0, 25, 50, 75, 100, and 125°C), higher current the higher temperature curve.

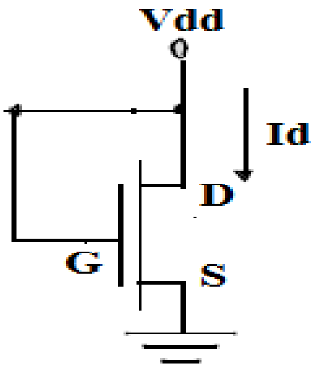

Figure 3. Connection of FinFET as a temperature nano sensor where Vd=Vg=1V.

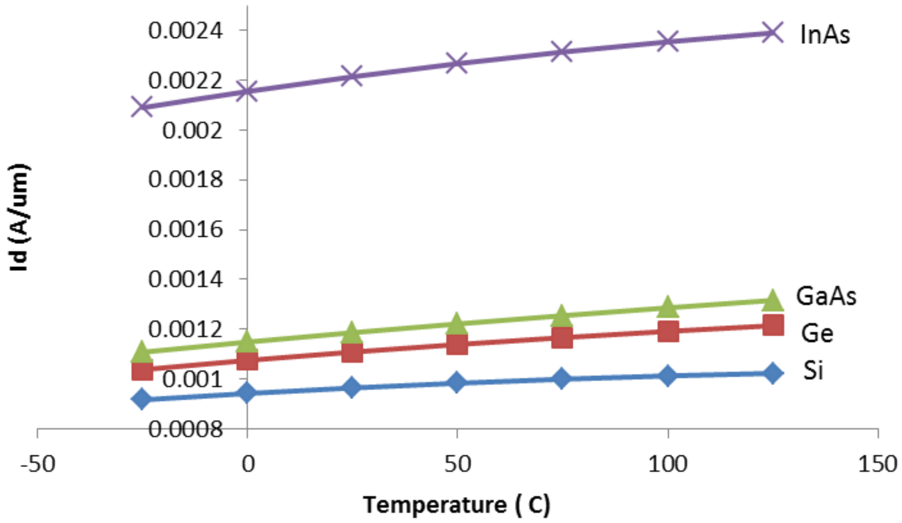

Figure 4. Id-Temperature characteristics with Vd=Vg=1V for FinFET at different semiconductor channel type

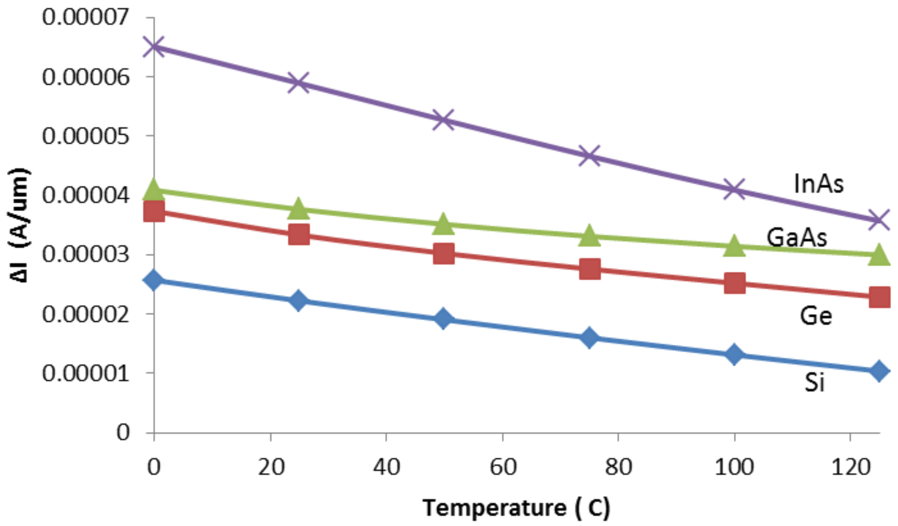

Figure 5. Current change (ΔI) -Temperature characteristics with Vd=Vg=1V for FinFET at different semiconductor channel type.

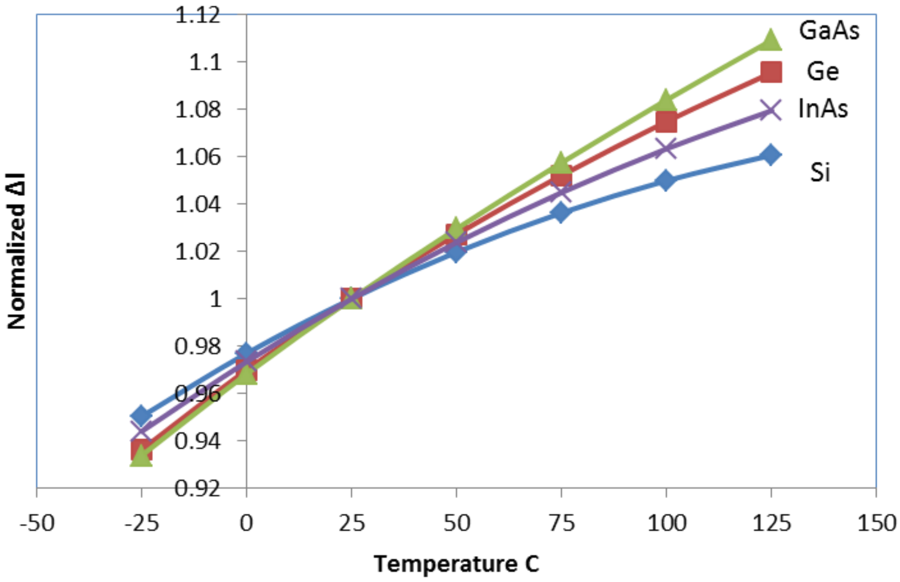

Figure 6. Normalized current change (ΔI) -Temperature characteristics with Vd=Vg=1V for FinFET at different semiconductor channel type.

Figure 7 illustrates the normalized (ΔI) [to ΔI at 25°C] as a percentage with temperature characteristics for FinFET at Vd=Vg=1V with different semiconductor channel type. This characteristic shows that the GaAs-FinFET (ΔI) increased up to 10.9% at 125°C of its value at 25°C, Ge-FinFET has an 9.5% (ΔI) increment at 125°C of its value at 25°C, InAs-FinFET has an 7.9% (ΔI) increment at 125°C of its value at 25°C, Si-FinFET has an 6% (ΔI) increment at 125°C of its value at 25°C.

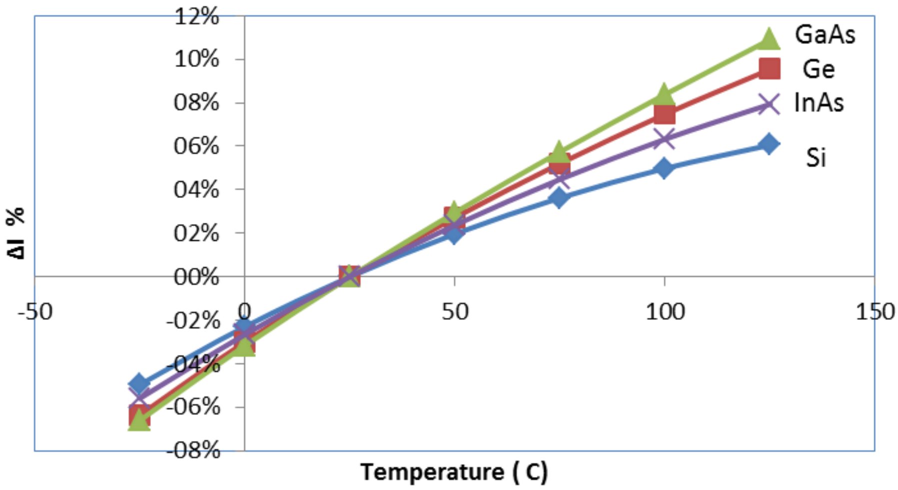

Figure 7. Percentage current change (ΔI %) -Temperature characteristics for FinFET at Vd=Vg=1V at different semiconductor channel type.

3. Conclusion

Temperature sensitivity of FinFET with (Si, Ge, GaAs, and InAs) as a semiconductor channel was simulated. Transfer characteristics of FinFET with V_d=1V was investigated at different values of operating temperature (-25, 0, 25, 50, 75, 100, and 125°C) for all types of semiconductor channel. The final results shows that the best FinFET used as a nano-sensor is with GaAs because it has the greatest ΔI (=10.9%) referring to ΔI at 25°C, and the best FinFET stable with increasing working temperature is Si-FinFET because it has the lowest ΔI (=6%) referring to ΔI at 25°C.

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Acknowledgment
The This work was supported by the University Malaysia Pahang (UMP) grant [RDU150360].

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