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Comparison Study Between SOI And Si MOSFET Based Inverter For EV Application Using MATLAB/Simulink

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Abstract: An electrical device known as an inverter transforms electricity from a direct current (DC) source into an alternating current (AC) that can be utilized to power a device or appliance. The necessity for electric vehicles (EVs) to convert the electrical current required to charge them into the direct current needed to operate them creates a few significant difficulties such as high voltage-related temperature increases. The system's temperature is likely to be increased since power is dissipated in the form of heat. The common material used for the electric vehicle inverter based on the previous study is Silicon Carbide. This paper focuses on the simulation model and calculation of losses by using two different materials which is Silicon on Insulator and Silicon. The switching and conduction losses were calculated using MATLAB/Simulink models of the devices. The results show that Silicon on Insulator MOSFET has lower conduction and switching losses and also for total power loss. It also shows that Silicon on Insulator MOSFET was superior compared to the Silicon MOSFET in terms of their overall characteristics.

Keywords: Silicon on Insulator, Silicon, Inverter, MOSFET, Electric Vehicle

1. Introduction

The first electric cars appeared in the middle of the 19th century. The land speed record for vehicles was held by an electric car until about 1900. Comparing battery electric vehicles to internal combustion engine vehicles from the 20th century, the high cost, limited peak speed and short range of battery electric vehicles have all decreased globally, public transportation particularly rail trains, as well as loading and freight equipment has continued to use an electric vehicle. At the beginning of the 21st century, interest in electric and another alternative fuel vehicle for private motor vehicles increased as a result of growing concern about the risks connected with vehicles powered by hydrocarbons. Include the harm that emissions do to the environment, the future feasibility of the current infrastructure for transportation powered by hydrocarbons and improvements in the field of electric vehicle technology. Various people are credited with developing the first model electric

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vehicle, Anyos Jedlik invented an early type of electric motor and created the small model car powered by his new motor.

The growing demand for hybrid electric vehicles necessitates new semiconductor product solutions. As networking becomes more common and chips are integrated more into vehicle design, car owners are expecting more comfort, convenience and high security. The development of Silicon on Insulator, a chip manufacturing technology, is a result of the hot engine world. A thin layer of Silicon (about 100nm thick), known as buried oxide is used to create Silicon on Insulator. Other than that, the development of technology and the desire for the most recent ising SOI technology will lead to quicker computer processors that also required less power, which is a crucial necessity for prolonging the battery life that will be prevalent in the future [1].

The design and fabrication of a Silicon on Insulator that can function at 200 °C ambient temperature. For continuous high-temperature operation, a prototype buck converter made of a SiC power module and SOI gate driver is constructed [2]. The power electronics module will have higher power-to-volume and power-to-weight ratios if the chip is able to operate at this temperature with or without a small heat sink and without cooling liquid [1].

The present study aims to demonstrate the modeling and simulation of SOI-based inverter with reliability studies on the system to enhance the performance for EV purposes. Therefore, the system is examined and implemented using MATLAB/Simulink.

2. Materials and Methods

The Silicon on Insulator MOSFET-based inverter is divided by two results which are electrical and output characteristics. Both results were simulated by using MATLAB/Simulink since it is easily used software and it is able to work efficiently.

2.1 SOI and Si MOSFET

Table 1 and Table 2 show electrical characteristics between both Silicon on Insulator and Silicon MOSFET under a junction temperature 25°C and these parameters were taken from the datasheet.

Table 1: Parameter specification for SOI and Si MOSFET

Parameter	SOI MOSFET	SI MOSFET
Static drain- source on-state resistance, $R_{DS(on)}$	0.15 Ω	0.27 Ω
Drain current, I_{DS}	10 A	7.8 A
Gate source voltage, V_{gs}	10 V	10 V
Input Capacitance, C_{iss}	1400 pF	830 pf
Reverse Transfer Capacitance, C_{rss}	0.5 pF	68 pf
Output Capacitance, C_{oss}	40 pF	15 pf

Table 2 shows the value for Turn-on and Turn-off switching loss for both SOI MOSFET and Si MOSFET calculated from the value acquired from Table 1. From the table, most of the value SOI MOSFET is lower than Si MOSFET except for the drain current value.

Table 2: Parameter specification for Silicon on Insulator (SOI) and Silicon (Si) MOSFET

Parameter	SOI MOSFET	Si MOSFET
Static drain- source on-state resistance, $R_{DS(ON)}$	0.15 Ω	0.27 Ω
Drain Current, I_{ON}	10 A	7.8 A
Turn-on switching loss, $EM_{(ON)}$	12.1875 µJ	156 µJ
Turn-off switching loss, $EM_{(OFF)}$	47.1250 µJ	156 µJ

2.2 Loss Calculation

A MOSFET's power loss is caused by two factors. Every MOSFET contains a resistive element, it dissipates power as current passes through it. The resistive parameter is describe as on-resistance, $R_{DS(on)}$. Conduction losses are inversely related to MOSFET size, the larger the switching transistor, the lower $R_{DS(on)}$ and thus the conduction loss. Switching losses are the other source of power loss. Equation 1,2,3 and 4 shows the conduction and switching loss calculation for SOI and Si MOSFET based inverter as the followed:

The formula for conduction loss are the product of static drain-source on-state resistance, $R_{DS(on)}$ and square of drain current, I_{ON}.

$$P_{CONDUCTION} = R_{DS(on)} \times I^2_{ON} \quad (1)$$

The formula for switching loss are switching frequency product with the sum of turn-on and turn-off switching loss

$$P_{SWITCHING} = f_s \left(E_{M,ON} + E_{M,OFF}\right) \quad (2)$$

The formula of one power loss MOSFET are the sum of conduction loss and switching loss. Since we are using six MOSFET, the formula will be timed by six.

$$P_{TOTAL} = P_{CONDUCTION} + P_{SWITCHING} \quad (3)$$

$$P_{TOTAL} = 6 \left(P_{CONDUCTION} + P_{SWITCHING}\right) \quad (4)$$

3. Results and Discussion

The simulation results for the materials used for this research, such as Silicon on Insulator and Silicon, are shown in the results and discussion section. MATLAB/Simulink software is used to model SOI and Si MOSFET and the output and transfer characteristics are simulated using the parameters taken from each datasheet for a range of voltages. The inverter circuit is configured to monitor the switching pulse and output waveforms and to verify their distinction. In order to assess the power dissipated in SOI and Si MOSFET-based inverters by analyzing the findings, loss percentage estimates for switching and conduction are therefore done using MATLAB code.

3.1 Output Characteristics of SOI and Si MOSFET

The output characteristics are seen to exhibit three operating regions which is the cut-off region, ohmic or linear region and saturation region. The cut-off region is a region in which MOSFET will be OFF when there is no current flow through it. For the ohmic or linear regions, the current I_{DS} increases with an increased value of V_{DS} such that they can be used as amplifiers. The saturation region has its I_{DS} constant despite an increase in V_{DS} and occurs when V_{DS} exceeds the value of pinch-off voltage V_P. Figure 3.1 and Figure 3.2 shows output characteristic for both MOSFET. The comparison of output characteristics between both MOSFETs is shown in Figure 1.

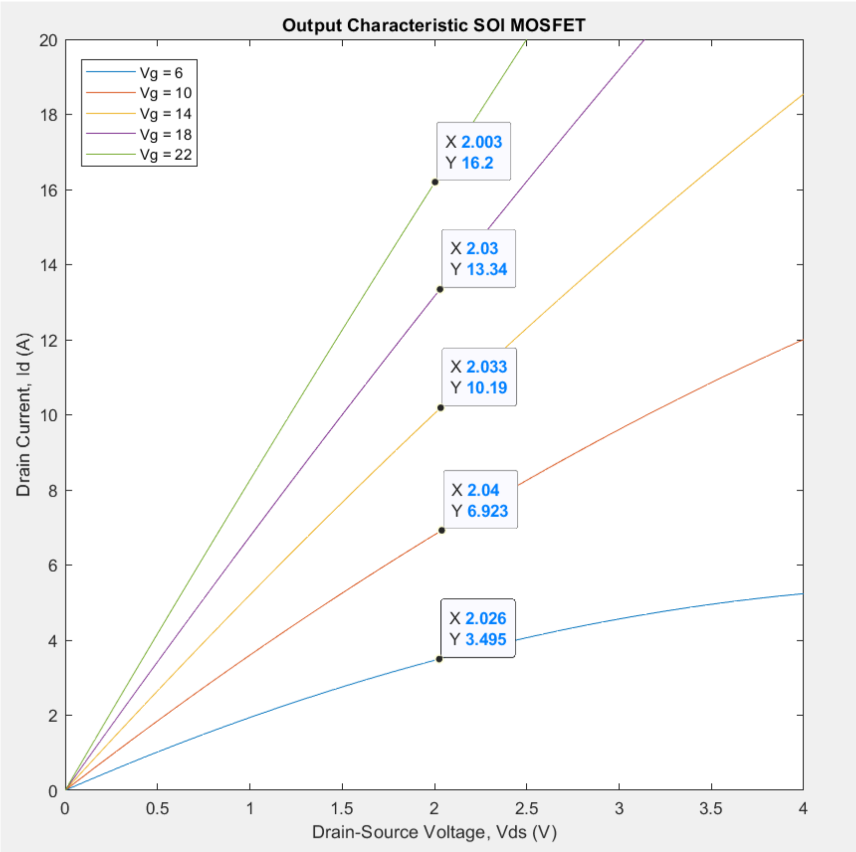

Figure 1: Output Characteristics for Silicon on Insulator (SOI) MOSFET

Figure 1 shows five different line styles which indicate a green line for 6 volts, purple line for 10 volts, yellow line for 14 volts, red line for 18 volts and blue line for 22 volts.

Figure 2 shows the graph of drain-source voltage against drain current with five indicators on it. The characteristic is measured with various gate voltages ranging from 6 V to 22 V. The blue line represents 22 volts, the red line indicates 18 volts while yellow line indicates 14 volts, the purple line represents 10 volts and the green line indicates 6 volts. The curves of the simulation model for Figure 3 show the Silicon MOSFET have lower output characteristic compared to the Silicon on Insulator MOSFET. At the range of 2.40 volts, it shows a different drain current, Id for both MOSFET which is 5.76 A.

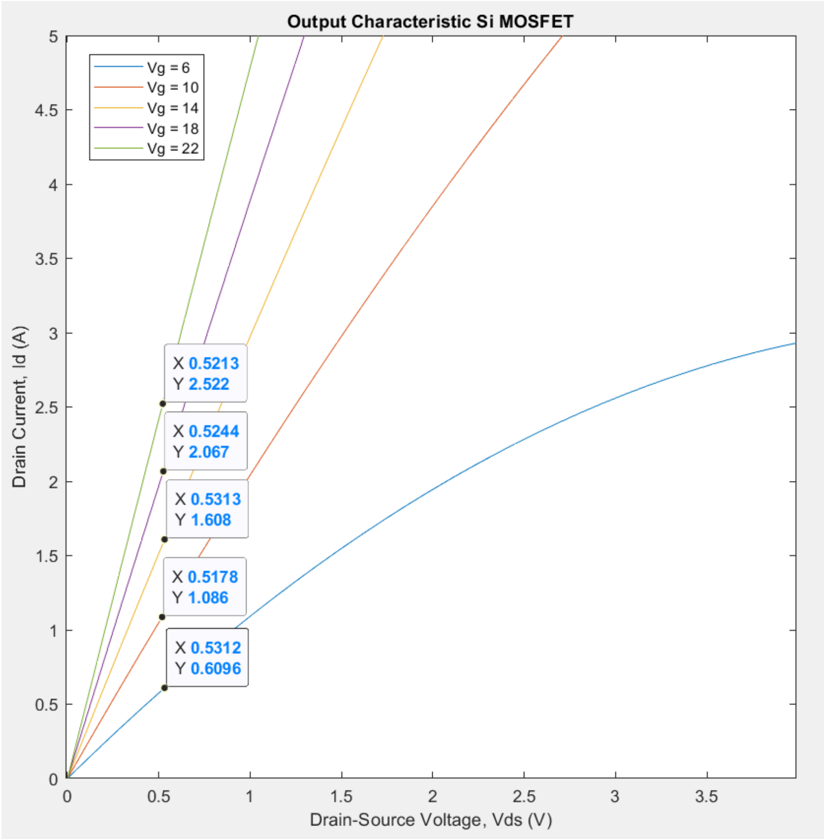

Figure 2: Output Characteristics for Silicon (Si) MOSFET

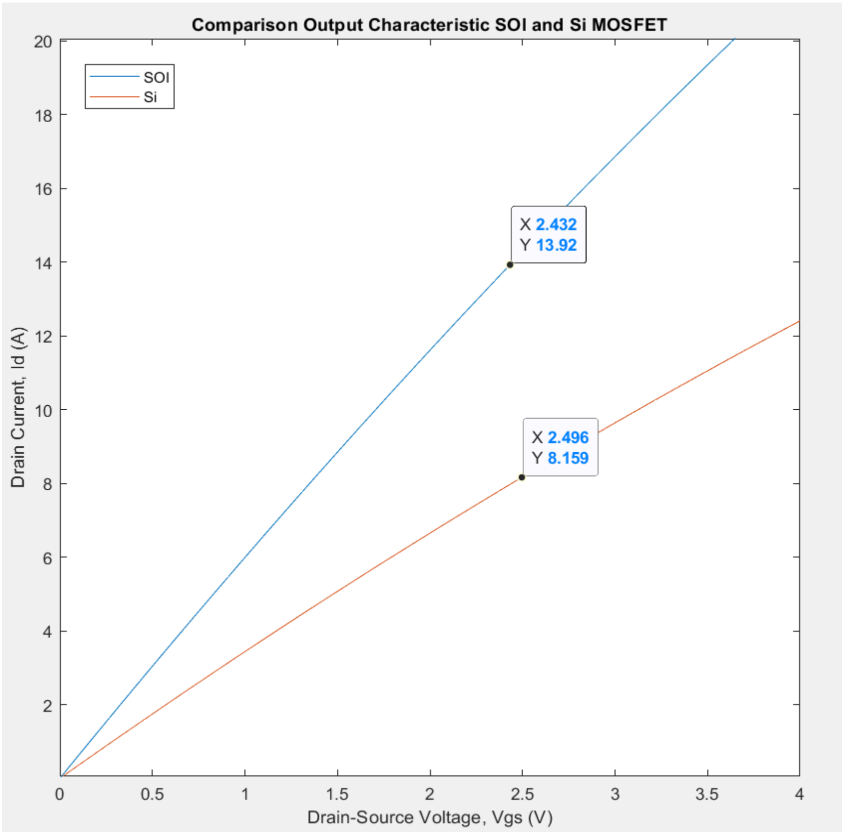

Figure 3: Comparison of Output Characteristics between Silicon on Insulator and Silicon MOSFET

3.2 Transfer Characteristics of SOI and Si MOSFET

The drain current is related to the input gate-source driving voltage which relates to the transfer characteristics. The gate current is initially zero because the gate terminal is electrically separated from the remaining terminals (drain, source and bulk), hence the gate current is not a device feature. The gate voltage at which the transistor passes current and exits the OFF state can be found using the transfer characteristics curve. The transfer characteristic graph of MOSFET is also used to determine the ohmic region of the MOSFET in the output characteristics graph. Figure 4 shows the comparison transfer characteristics graph for both Silicon on Insulator (SOI) and Silicon (Si) MOSFET.

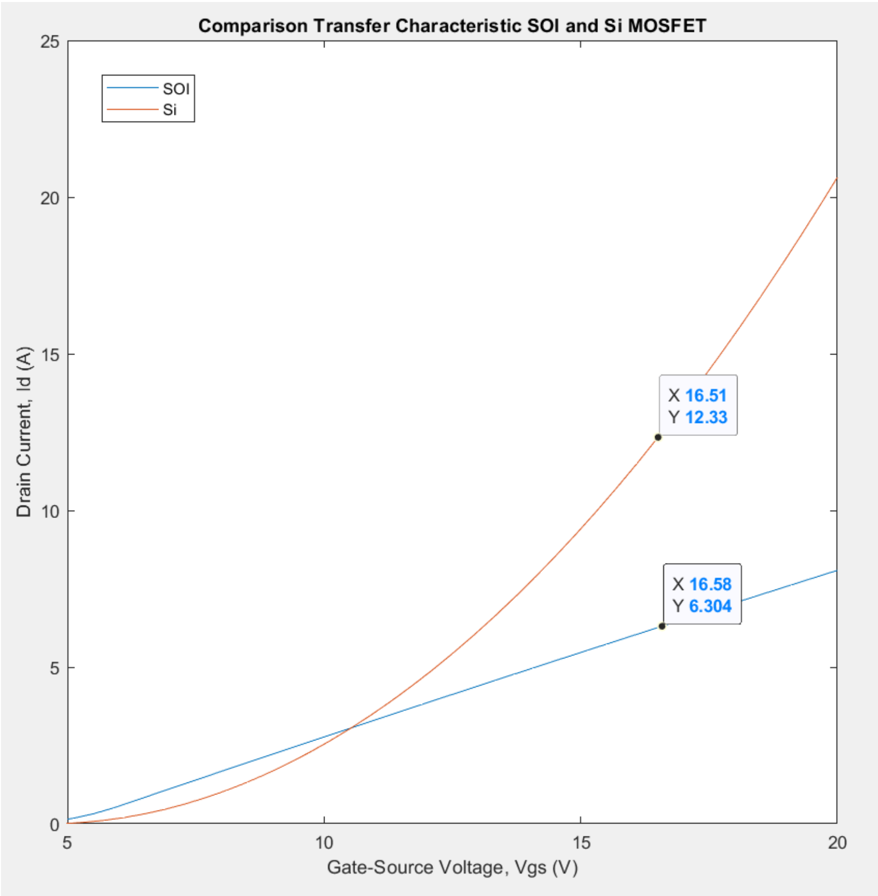

Figure 4: Comparison of Transfer Characteristics Between Silicon on Insulator and Silicon MOSFET

From Figure 4, it can be seen that the blue line indicates the Silicon on Insulator MOSFET while the red line indicates Silicon MOSFET. At 10.51 volts, the Silicon MOSFET reaches the same saturation as the Silicon on Insulator but the value continues to exceed the Silicon on Insulator MOSFET. The Silicon on Insulator shows a linear function while Silicon is nonlinear. When the voltage at the range of 16.50 volts, the difference between the drain current, Id of both MOSFETs is 6.02 A.

3.3 Loss calculation (%) of switching and conduction for SOI and Si MOSFET-based inverter.

The comparison between SOI and Si MOSFET-based inverter for loss calculation in Table 3 proved that the use of Silicon on an Insulator can reduce more losses in the operation of an inverter compared to Silicon [12]. Table 3 shows the value of conduction loss and loss reduction gained between Silicon on Insulator and Silicon MOSFET. It shows a significant loss reduction value between the MOSFET which is 8.68%. These losses are inversely proportional to the size of the MOSFET, the larger the switching transistor, the lower its $R_{DS(on)}$ and therefore its conduction loss.

Table 3: Conduction loss reduction between Silicon on Insulator and Silicon MOSFET.

Parameter	SOI MOSFET	SI MOSFET	Loss Reduction (%)
Conduction Loss (W)	15	16.4268	8.68

Table 4 and Table 5 show the switching loss reduction based on the switching frequency and comparison of total inverter loss for Silicon on Insulator MOSFET and Silicon MOSFET. The data from table 4 shows that Silicon on Insulator MOSFET has a larger value for the switching loss compared to Silicon MOSFET. The loss reduction between the MOSFET maintains at 80.98 % even though the switching frequency increasing. The comparison between both MOSFETs shows that Silicon on Insulator MOSFET has good performance since it has a lower value for total inverter loss compared to Silicon MOSFET.

Table 4: Switching loss reduction between Silicon on Insulator and Silicon MOSFET

Switching Frequency (Hz)	Switching Loss (μW)		Loss Reduction (%)
	SOI MOSFET	Si MOSFET	
50	2965.62	15600	80.9896
75	4448.43	23400	80.9896
100	5931.25	31200	80.9895
125	7414.06	39000	80.9895
150	8896.87	46800	80.9895
175	10379.68	54600	80.9895
200	11862.50	62400	80.9895

Table 5: Comparison of total inverter loss for Silicon on Insulator and Silicon MOSFET

Switching Frequency (Hz)	Total Inverter Loss (W)	
	SOI MOSFET	Si MOSFET
50	90.0177	98.6544
75	90.0266	98.7012
100	90.0355	98.7480
125	90.0444	98.7948
150	90.0533	98.8416
175	90.0622	98.8884
200	90.0711	98.9352

4. Conclusion

The experimental evaluation of a Silicon on Insulator (SOI) MOSFET-based inverter for electric vehicle (EV) application was carried out by using MATLAB/Simulink. The results show an outstanding outcome through simulating, designing and calculating the losses of the inverter. The datasheet for both MOSFETs is important since it contains a parameter that will be implemented into the MATLAB/Simulink software. Without the datasheet, the value for switching and conduction loss are not able to be gained. The performance between the Silicon on Insulator and Silicon MOSFET-based inverter offers inherent advantages in microelectronics, especially in lower power consumption compared to Silicon-based inverter since it is able to reduce overall inverter loss by 8.68 %. While the loss reduction between Silicon on Insulator and Silicon MOSFET is in the range of 80.98 %.

The results indicated that Silicon on Insulator MOSFET-based inverter has a lower conduction loss and higher switching loss conflicting to Silicon MOSFET-based inverter due to its low on-resistance. One of the advantages of Silicon MOSFET-based inverter over Silicon MOSFET counterparts is its ability to operate in a very high-speed switching due to its lower parasitic capacitances [13]. In conclusion, the software is able to simulate the Silicon on Insulator and Silicon MOSFET-based inverter. From that result, we can conclude that the objective is achieved since Silicon on Insulator MOSFET based inverter has the lower power consumption.

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