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DESIGN AND IMPLEMENTATION OF GALLIUM NITRIDE BASED SEMICONDUCTOR IN BOOST CONVERTER

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Abstract.Power electronics is the process of applying solid-state devices like transistors, Mosfet, diodes etc for controlling and converting electric power. They are used in the fields such as telecommunication, utility systems, facts, residential. Most of the power electronic devices are made up of Silicon semiconductor. Silicon has high breakdown electric field strength and so it can configure to withstand hey more than hey 600 to 1000 volts [4]. Even though there are many benefits in silicon, the increased heat generation decreases the efficiency of the device. It is caused due to switching loss. A new semiconductor called gallium nitride is being used to eradicate the disadvantages of silicon. Gallium nitride has high electron mobility and high saturation electron velocity compared to silicon and so it enables them to function over 250 GHz [1]. Since the semiconductor has wide bandgap, they are not sensitive to heat. Through this project, we can obtain efficiency between Two semiconductors by comparing its switching characteristics in boost converter.

1. Introduction

A power electronic switching device is a combination of active switchable power semiconductor drivers that integrates into one. [3]. Silicon is a compound semiconductor. Silicon provides 10 times the breakdown electric field, three times the bandgap [5]. The drift layer resistance per area can be reduced 300 times the withstand voltage. In order to decrease the increase in on resistance at higher with stand voltages, minority charge devices (bipolar) such as IGBT is typically used. However, the increase in switching loss decreases the efficiency of the silicon Mosfet by increasing the heat during the process.

A new semiconductor called as gallium nitride semiconductor is used. Gallium nitride is capable of carry high current. Combined with high dielectric constant, it brings enormous features for IC [8]. It has made it an ideal material for MMIC [7]. It has the ability to achieve greater withstand voltages with extremely lower on resistance per unit area.

2. Semiconductor Technology

The semiconductor technology deals with the brief explanation about the Silicon based mosfet and Gallium Nitride based mosfet.

A. Silicon Mosfet (IRf 840)

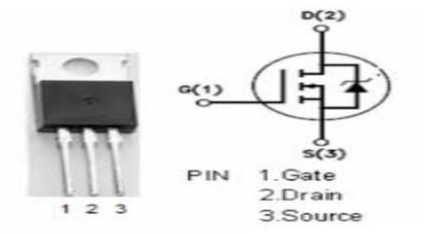

Fig. 1. Silicon Mosfet (IRF 940)

Silicon (Si) MOSFET exhibit higher blocking voltage, lower on state resistance and higher thermal conductivity [4]. As shown in Fig 1, Due to its simple structure, ease of a design-in and low drive losses, the N-channel enhancement mode in Si MOSFET offers good compatibility as a replacement for silicon MOSFET and IGBT[6] .This power MOSFET is designed for applications such as switching regulators, switching converters, motor drivers, relay drivers, and drivers for high power bipolar switching transistors requiring high speed and low gate drive power.

PARAMETERS	SYMBOL	LIMIT	UNIT
Drain-Source Voltage	Vds	500	V
gate-source voltage	Vgs	20	V
drain current	Id	8	A
power dissipation	Pd	125	W
pulsed drain current	Idm	32	A

Table 1. SILICON MOSFET SPECIFICATION

I. ADVANTAGES OF SILICON MOSFET

The advantages of silicon mosfet includes

- Higher efficiency at lower voltages.
- It provides larger bandgaps, higher breakdown electric field, and higher thermal conductivity.

II. Disadvantages of Silicon Mosfet

The disadvantages of silicon mosfet includes

- The span of Mosfet is low
- Overload voltages makes it unstable.

III. Applications of Silicon Mosfet

The applications of Silicon mosfet includes

- Switch
- Amplifier
- Voltage regulator

B. Gallium Nitride Mosfet

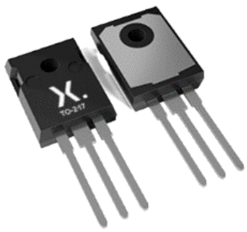

Fig 2. Gallium Nitride Mosfet (GAN063650WSA)

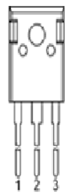

Fig 3. Pin configuration of GaN Mosfet (GAN063650WSA)

1. gate
2. source
3. drain

Gallium nitride or GaN is the new semiconductor technology which provides high speed process, increased efficiency when compared with silicon MOSFET [4]. GaN's provides MHz switching frequency operation to increase efficiency [2]. As shown in Fig 2, GaN increases the efficiency by reducing the switching loss than its silicon counterparts. Utilization of gallium nitride (GaN) in the industry has soared in recent years, with the technology now playing a key role in applications across the board.

Symbol	Parameter	Conditions		Min	Max	Unit
V_{DS}	drain-source voltage	-55 °C ≤ T_j ≤ 175 °C		-	650	V
V_{TDS}	transient drain to source voltage	pulsed; t_p = 1 μs; δ_{factor} = 0.01		-	800	V
V_{GS}	gate-source voltage			-20	20	V
P_{tot}	total power dissipation			-	143	W
I_D	drain current			-	34.5	A
				-	24.4	A
I_{DM}	peak drain current			-	150	A
T_{stg}	storage temperature			-55	175	°C
T_j	junction temperature			-55	175	°C

TABLE 2. GaN MOSFET SPECIFICATION

I. ADVANTAGES OF GALLIUM NITRIDE MOSFET

- GaN reduces switching losses by 80%, increasing the system efficiency.
- GaN MOSFET have shorter distance between the source and drain, which translates to lower resistance (reduced conduction losses).
- It is very cost effective.

II. APPLICATIONS OF GALLIUM NITRIDE MOSFET

- Automotive applications
- Space applications
- DC-DC conversion
- Wireless power
- Envelope tracking

3. BOOST CONVERTER CONFIGURATION

A. boost converter using silicon mosfet

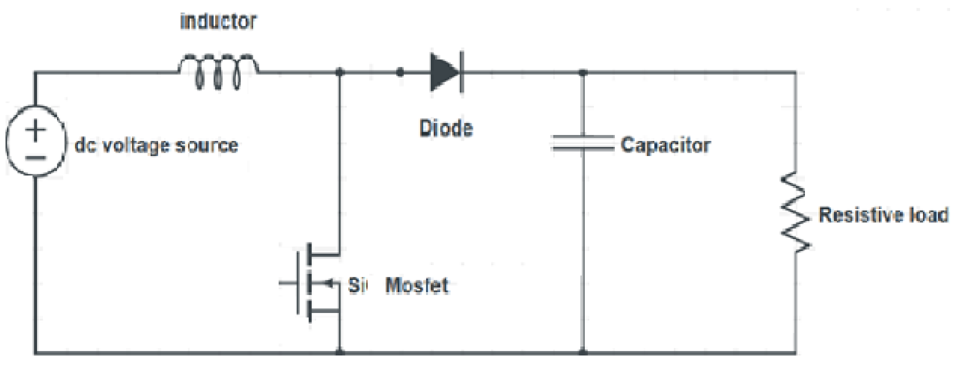

Fig 3. Boost converter using silicon mosfet

Fig 4. EXPERIMENTAL SETUP OF SILICON MOSFET

As shown in Fig 3 and Fig 4, the power semiconductor switch being used here is silicon. The source is provided by dc source. To store the charges, inductor and capacitor is used. Pulse generator is used to trigger the firing angle for MOSFET. The type of load used here is resistive load.

B. boost converter using Gallium Nitride mosfet

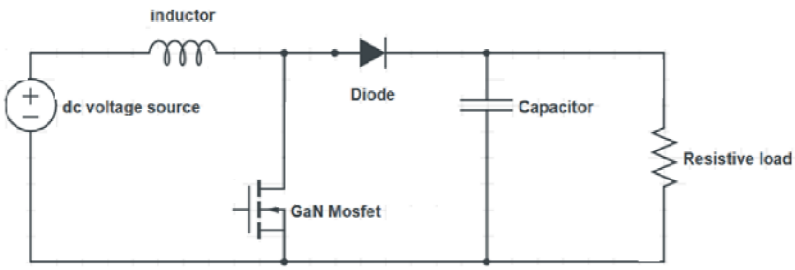

Fig 5. Boost converter using Gallium Nitride

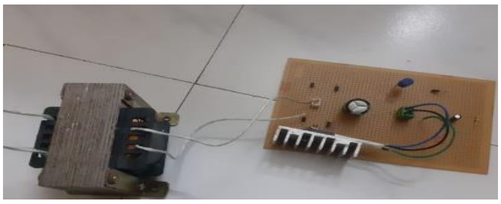

Fig 6. EXPERIMENTAL SETUP OF GALLIUM NITRIDE

As shown in Fig 5 and Fig 6, the power semiconductor switch being used here is Gallium Nitride. The source is provided by dc source. To store the charges, inductor and capacitor is used. Pulse generator is used to trigger the firing angle for MOSFET. The type of load used here is resistive load.

4. Simulation Analysis

The following simulation diagrams describes about the Silicon and Gallium nitride switches that are implemented in boost converter respectively.

i. SIMULATION OF SILICON MOSFET

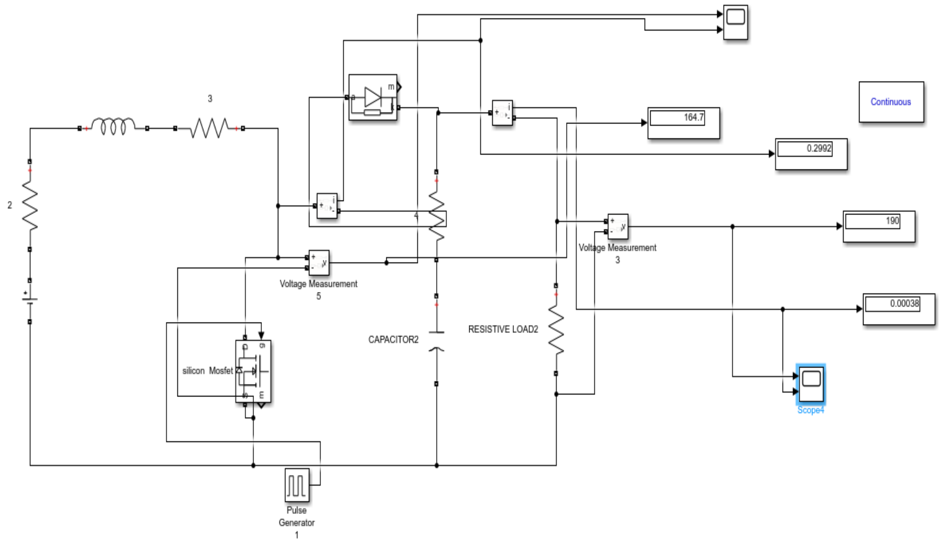

Fig 7 simulink of boost converter with silicon as mosfet

As shown in Fig 7, the inductor value is assigned as 1 milli henry. The capacitor is assigned as 1 micro farad. The value of resistive load is 500 K ohms. The switching frequency is 100 kilo hertz. The snubber resistance and capacitance is 59.75 ohm and 33.45 nf.

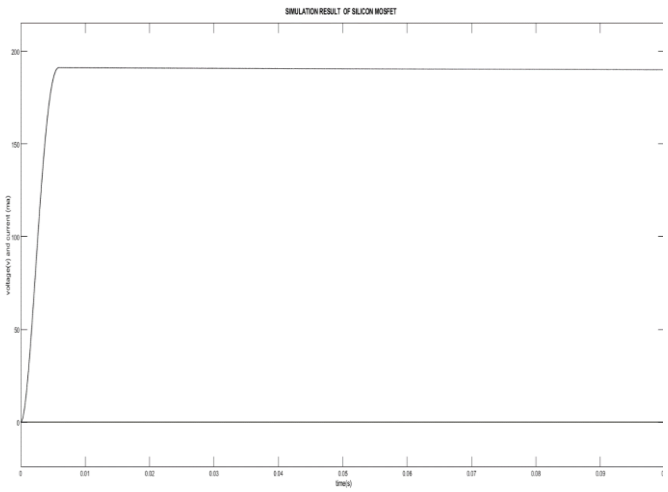

Fig 8 SIMULATION GRAPH OF SILICON MOSFET

ii. SIMULATION OF GALLIUM NITRIDE MOSFET

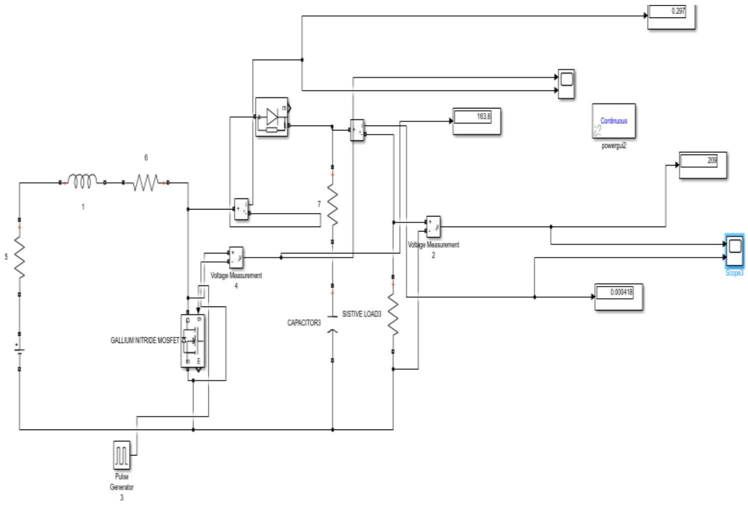

Fig 9. simulink of boost converter with GaN as mosfet

As shown in fig 9, The inductor value is assigned as 1 milli henry. The capacitor is assigned as 1 micro farad. The value of resistive load is 500 K ohms. The switching frequency is 100 kilo hertz. The snubber resistance and capacitance is 115.94 ohm and 17.25 nf.

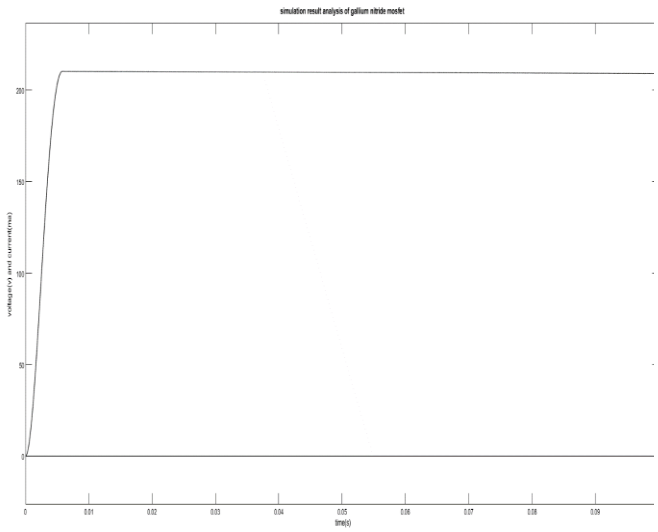

Fig 10: SIMULATION RESULT OF GALLIUM NITRIDE MOSFET

- **Observation from Simulation Analysis**
  When we compare fig 8 and fig 10, we observe that by keeping the pulse width to 90, The output voltage of Gallium Nitride (209 V) is relatively higher than output voltage of silicon (190 V). This is one of the evidences to show that efficiency of Gallium Nitride Mosfet is higher than Silicon Mosfet.

5. RESULTS AND DISCUSSIONS OF THE SYSTEM

Through the MATLAB and boost converter, various characteristics has been compared and its results are presented in the form of graphical presentation. Fig (11,12,13,14,15) and table (3,4,5,6,7) are the results obtained MATLAB whereas fig (16,17,18,19,20) and table (8,9,10,11,12) are obtained from boost converter.

A. MATLAB Results

I. Vds vs Id of Silicon Mosfet

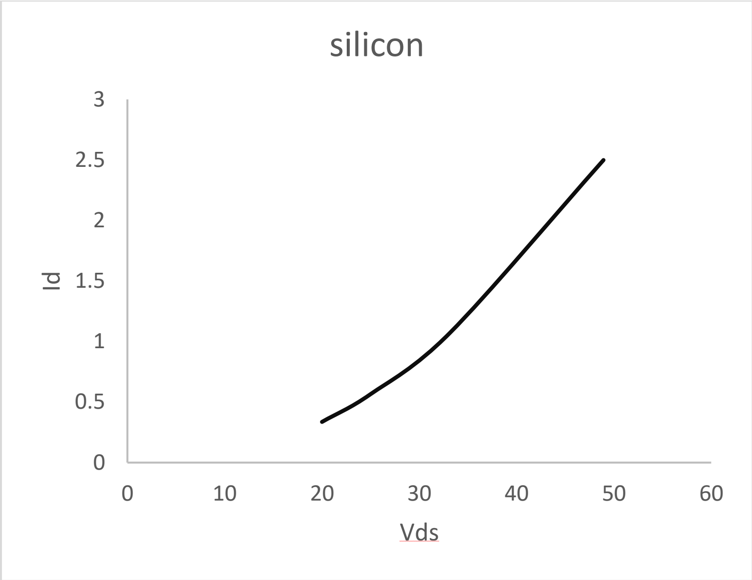

Fig 11. Vds VS Id of SILICON MOSFET

Vds	id
20	0.3361
24.96	0.5636
33.13	1.07
48.93	2.499

TABLE 3. Vds vs Id for silicon

II. Vds VS Id FOR GALLIUM NITRIDE

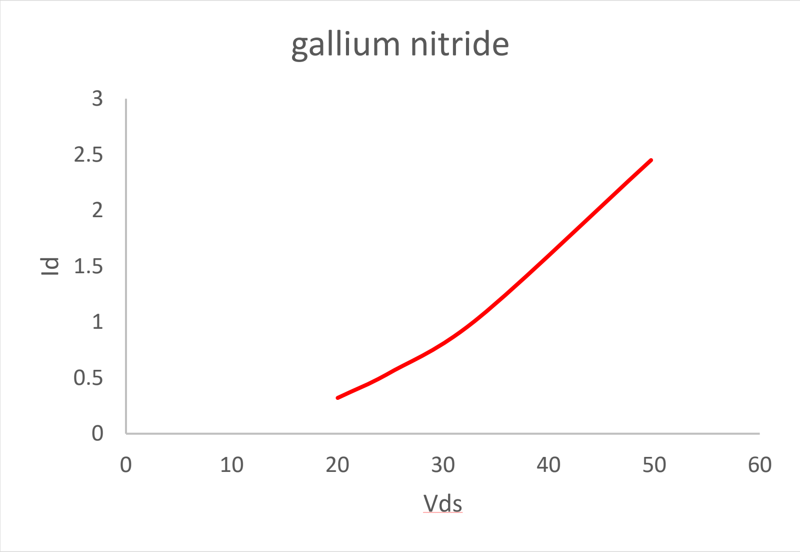

Fig 12. Vds VS Id FOR GALLIUM NITRIDE

Vds	id
20.04	0.3205
25.04	0.5493
33.33	1.033
49.71	2.45

TABLE 4. Vds vs Id for gallium nitride

iii. Pulse width vs Output voltage

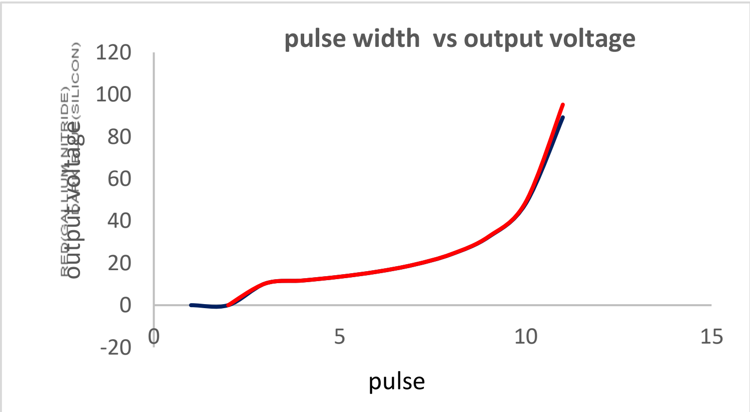

Fig 13. Pulse width vs output voltage

TABLE 5. pulse width vs output voltage

pulse	output voltage	
	silicon	gallium nitride
10	10.32	10.32
20	11.71	11.71
30	13.5	13.5
40	15.88	15.89
50	19.2	19.24
60	24.16	24.24
70	32.33	32.53
80	48.13	48.91
90	89.17	95.21

iv. Resistive load vs output voltage

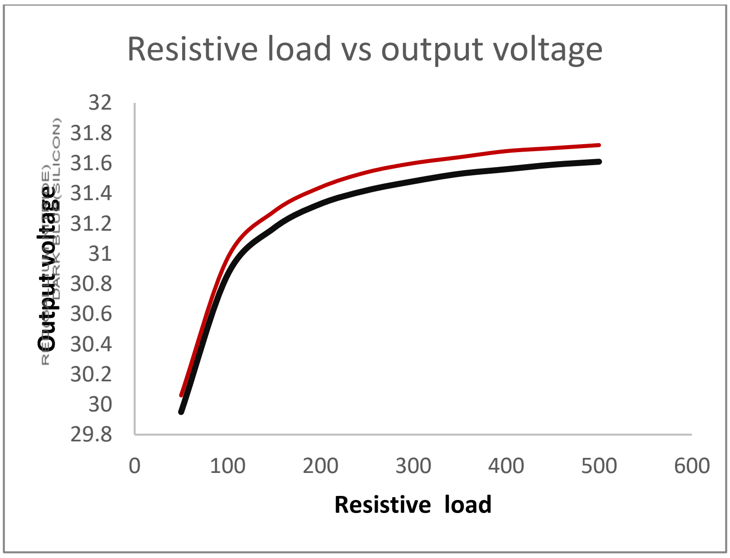

Fig 14. resistive load vs output voltage

resistive load (Kohm)	output voltage	
	silicon	Gallium Nitride
50	29.95	30.06
100	30.86	30.97
150	31.17	31.28
200	31.33	31.44
250	31.42	31.54
300	31.48	31.6
350	31.53	31.64
400	31.56	31.68
450	31.59	31.7
500	31.61	31.72

TABLE 6. resistive load vs output voltage

v. Pulse width vs conduction loss

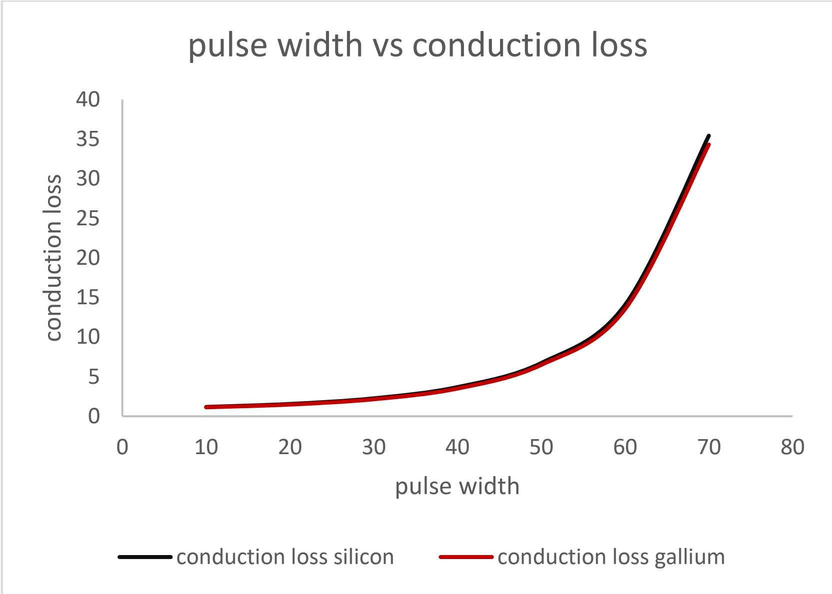

Fig 15. Pulse width vs conduction loss

pulse		conduction loss	
	silicon	gallium nitride	
10	1.1742	1.1264	
20	1.5499	1.4724	
30	2.259	2.1421	
40	3.6762	3.4948	
50	6.722	6.4869	
60	14.067	13.529	
70	35.44	34.32	

TABLE 7. pulse width vs conduction loss

B. Boost converter results

i. Vds vs Id for silicon Mosfet

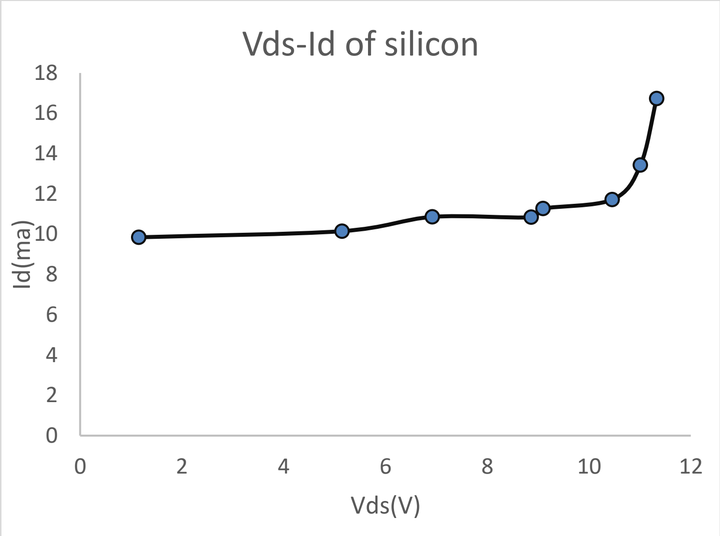

Fig 16. Vds VS Id of SILICON MOSFET

Vds(V)	Id(ma)
1.152	9.846
5.145	10.15
6.922	10.86
8.866	10.84
9.101	11.27
10.46	11.72
11.01	13.42
11.33	16.73

TABLE 8. Vds vs Id for silicon

ii. Vds VS Id FOR GALLIUM NITRIDE

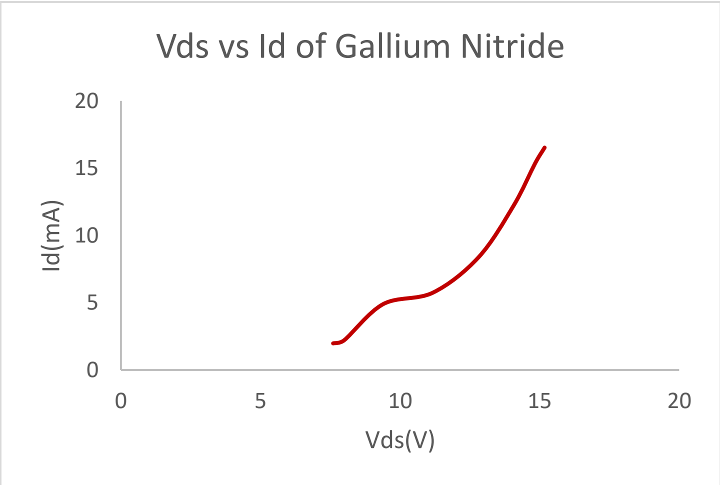

Fig 17. Vds VS Id FOR GALLIUM NITRIDE

Vds(V)	Id(mA)
7.601	1.978
7.998	2.21
9.395	4.895
11.18	5.75
12.81	8.369
14.07	12.22
14.84	15.36
15.18	16.53

TABLE 9. Vds vs Id for gallium nitride

iii. PULSE WIDTH VS OUTPUT VOLTAGE

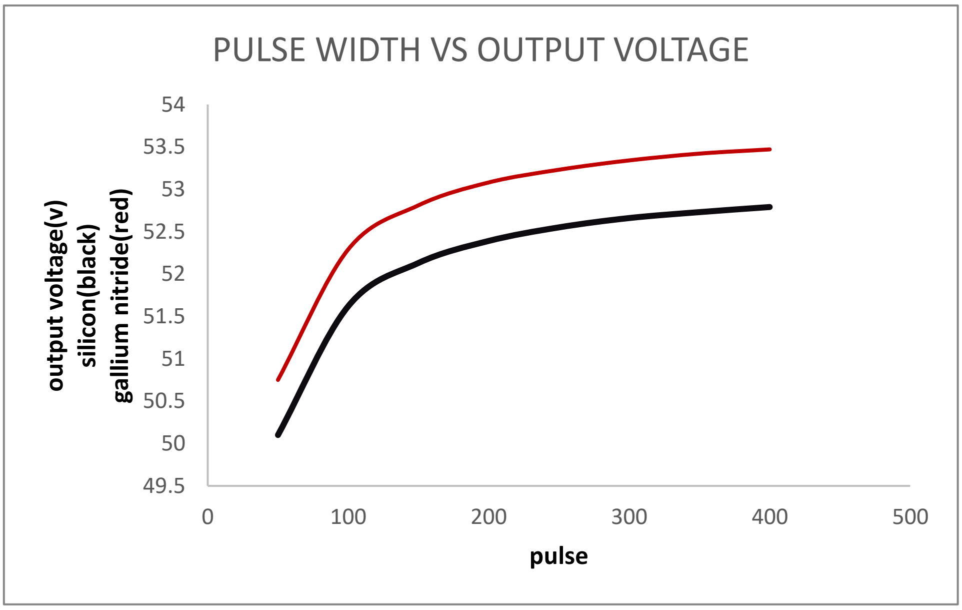

Fig 18. PULSE VS OUTPUT VOLTAGE

pulse	Vo(silicon)	Vo(GALLIUM NITRIDE)
15	31.78	31.89
20	33.73	33.88
25	35.93	36.12
30	38.41	38.66
35	41.26	41.59
40	44.54	44.95
45	48.36	48.69
50	52.87	53.55

TABLE 10. Pulse width vs output voltage

iv. Resistive load vs output voltage

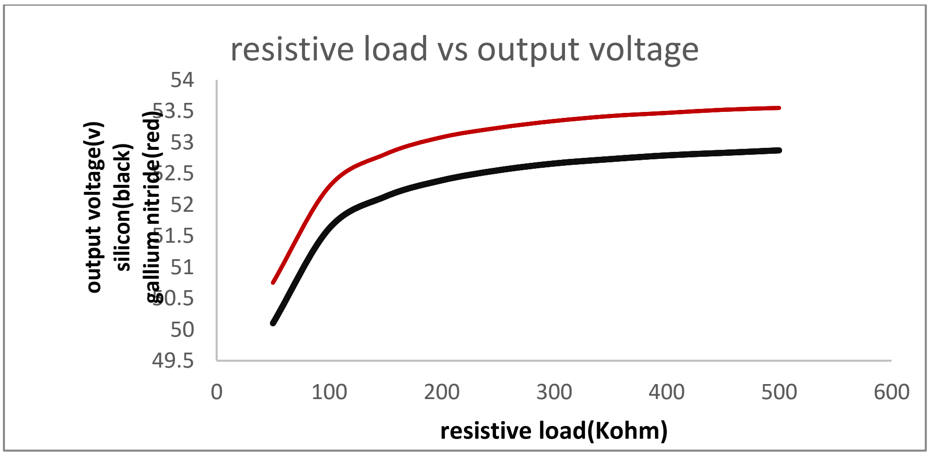

Fig 19. resistive load vs output voltage

resistive load (K ohm)	output voltage	
	silicon	gallium
50	50.1	50.75
100	51.62	52.29
150	52.13	52.81
200	52.39	53.08
250	52.55	53.23
300	52.66	53.34
350	52.73	53.42
400	52.79	53.47
450	52.83	53.52
500	52.87	53.55

TABLE 11. resistive load vs output voltage

v. pulse width vs conduction loss

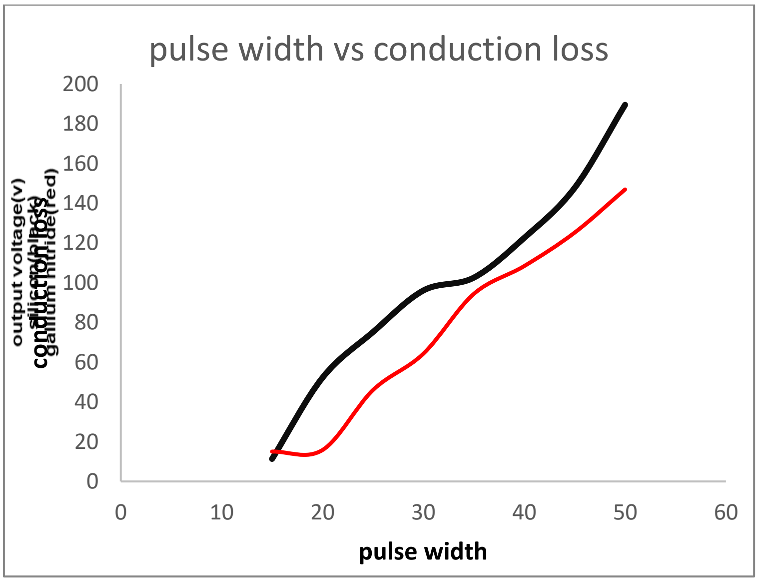

Fig 20. Pulse width vs conduction loss

Pulse width	conduction loss(silicon)	conduction loss (gallium nitride)
15	11.342	15.03
20	52.22	15.82
25	75.17	45.98
30	96.107	64.28
35	102.56	94.38
40	122.59	108.39
45	147.75	125.24
50	189.55	146.96

TABLE 12. pulse width vs conduction loss

6. Conclusion

Through these graphical comparisons, it is observed that

- By keeping the switching frequency constant for Silicon and Gallium Nitride Mosfet as 1 Khz and varying the pulse width for both the Mosfet, the drain-source drain current is obtained.

- Multiplying Vds and Id provides the power dissipated. The power dissipated by Silicon is more than Gallium Nitride.

- By varying the pulse width, the output voltage of GaN is greater than Silicon Mosfet.

- By varying the resistive load, the output voltage of GaN is greater than Silicon Mosfet.

- By varying the pulse width, the conduction loss of GaN is slightly less than Silicon Mosfet.

From these results, we conclude that the Gallium Nitride is more efficient than Silicon mosfet.

7. ACKNOWLEDGEMENTS

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