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GaN, SiC or Silicon Mosfet
A Comparison Based On Power Loss Calculations

Shishir Rai
Founder & CEO
DiscoverEE Inc.

Website: www.discoveree.io | Email: rai@discoveree.io
Address: 100 Pine St., Ste. 1250, San Francisco, CA 94111

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Introduction

Shishir Rai

Founder @DiscoverEE, California, USA

Sr. Manager, Automotive Product Marketing
@Vishay Siliconix, California, USA

System/Applications Engineer
Analog IC Design Engineer
Power Device R&D Engineer
@Infineon Technologies, California, USA

M.S. EE (Focused on III-V WBG Devices)
@ University of Notre Dame, Indiana, USA

B.Tech. Electrical Engineering
@ Indian Institute of Technology, Madras, India

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Presentation Highlights

In this paper, we analyze Silicon, GaN and SiC power transistors under the same circuit conditions.

We consider a 3 kW DC-DC power converter which operates with input of 400 V / 15 A and 800 V / 7.5 A at switching frequencies ranging from 1 – 200 kHz.

Using the power loss dashboard, we quickly identified 4000 Si, SiC and GaN power transistors that match our criteria from ~25,000 that are available in the market.

We compare the calculated power loss trends at different operating conditions of voltage, current, switching frequency while delivering the same amount of power.

We determine which devices offers the lowest power loss performance for their price. The study will help hardware engineers rapidly identify which devices are best for their applications.

Circuit Conditions & Power Loss Requirement

Circuit Condition:

Vds = 400 V & 800 V

Ids = 15 A & 7.5 A

Fsw = 1, 10, 20, 100, 200 kHz

Duty cycle = 0.5

Rg total = 10 Ω (external + internal)

Tambient = 25 C

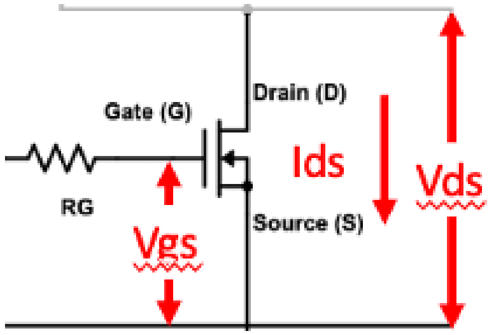
Gate drive = 10 V

Total Power Loss (Requirement: ≤40 W)

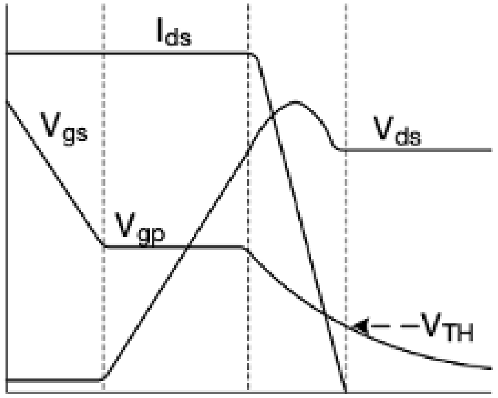
Conduction= $I_{ds}^2 * R_{ds(on)} * D$

Switching = $F_{sw} * I_{ds} * V_{ds} * (t_{on} + t_{off})/2$

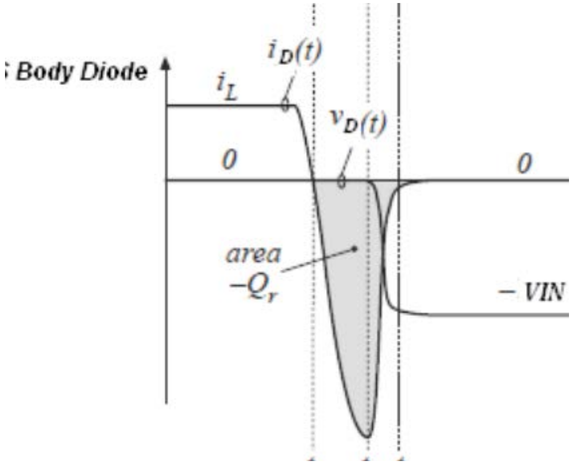
Diode Reverse Recovery = $Q_{RR} * V_{ds} * F_{SW}$



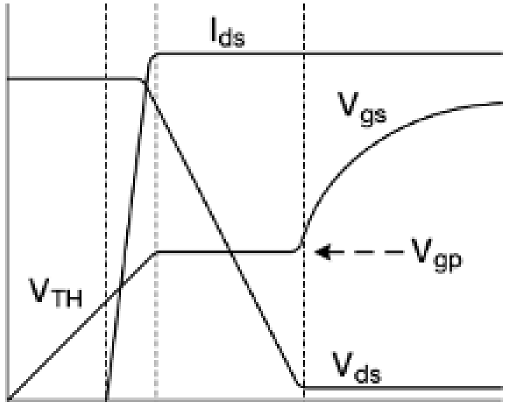
Switching MOSEET



Turn-Off Transient Waveform



Diode Reverse Recovery



Turn-On Transient Waveform

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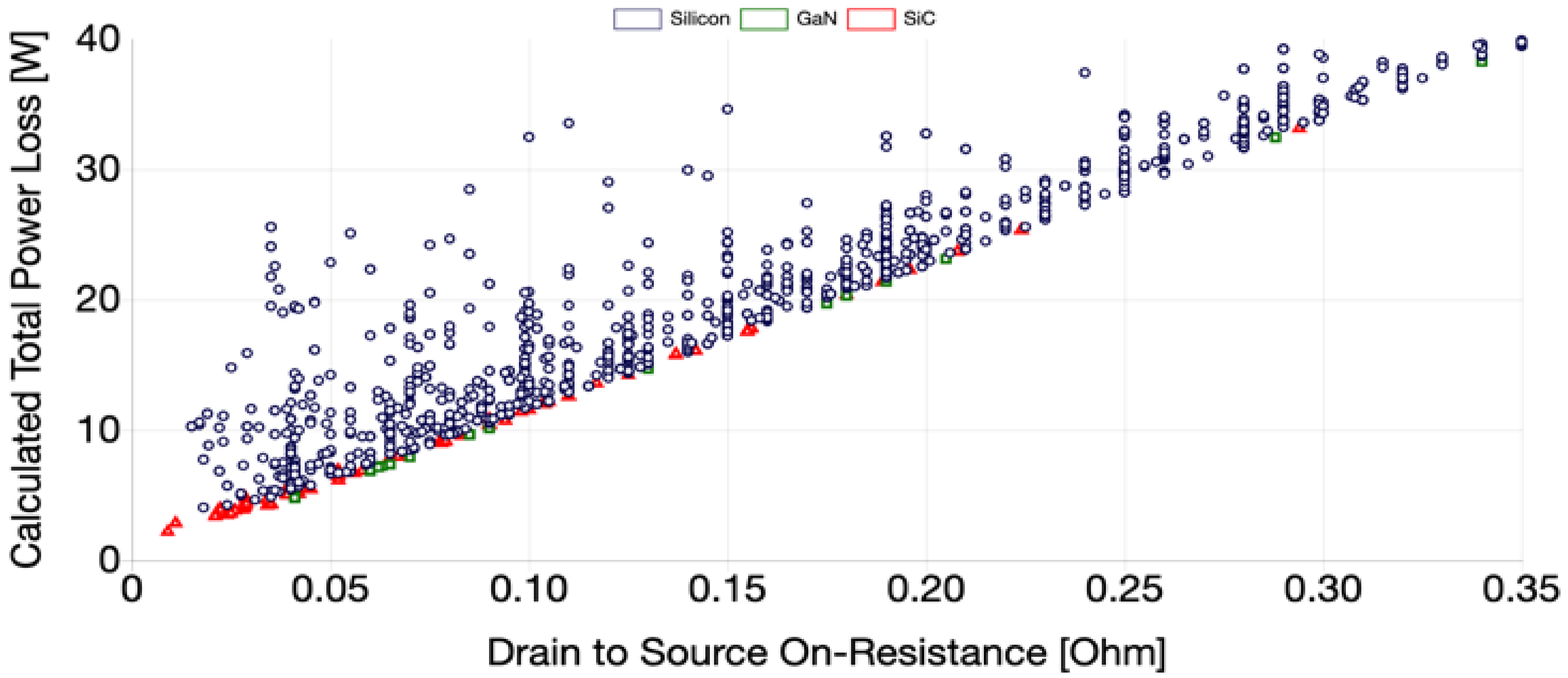

Power Loss Dashboard

- We considered ~25,000 Mosfets from over 30 manufacturers in 750+ package types to create a power loss dashboard.
- Blue circle represents Silicon Mosfet, green square represents GaN FET and red triangle represents SiC FET.

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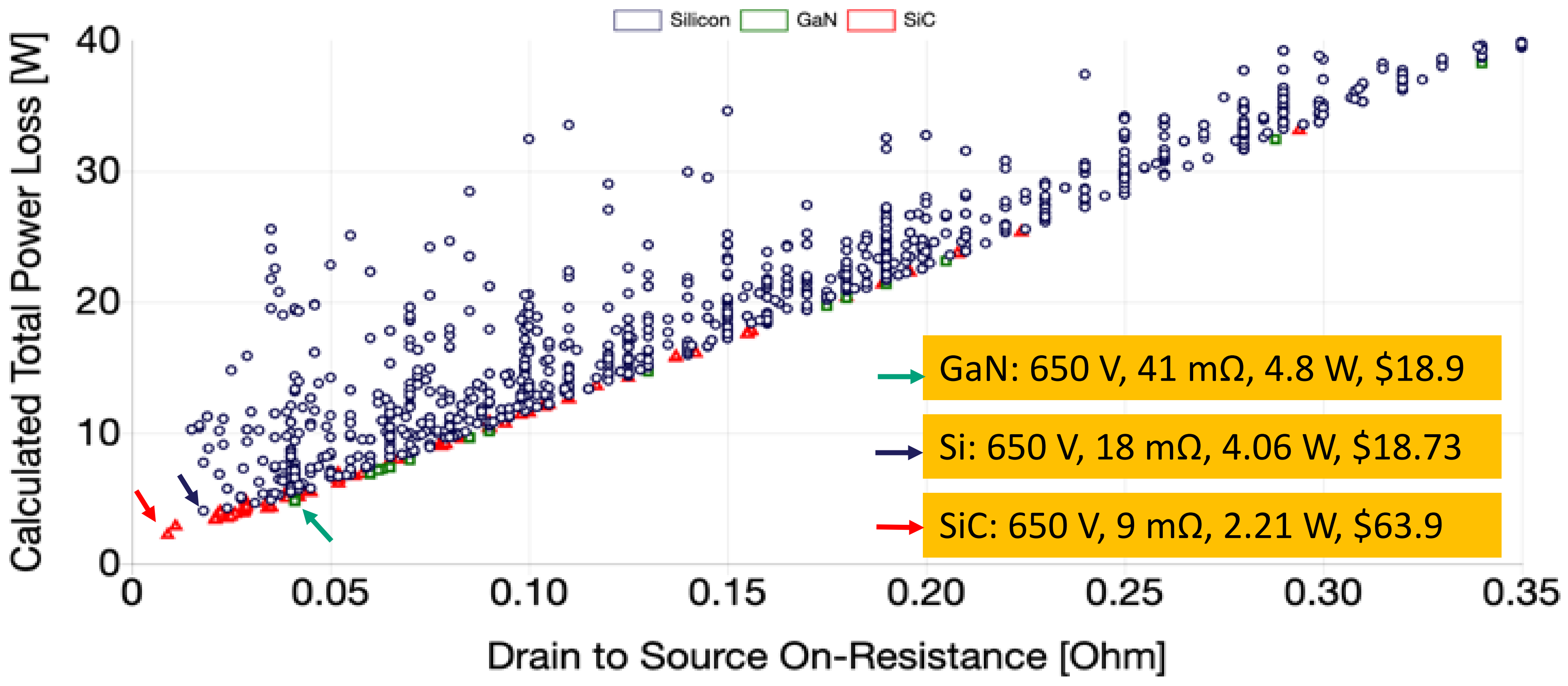
Results for Operation at 400 V, 15 A, D=0.5 from 1-200 kHz

- For a hypothetical 3 kW power converter, consider the first set of operating conditions V_{DS} = 400 V, I_D = 15 A, D = 0.5, $R_{G\ Total}$ = 10 Ω, T_{AMB} = 25 °C and V_{GS} = 10 V at F_{SW} of 1 kHz, 10 kHz, 20 kHz, 100 kHz and 200 kHz with requirement of device breakdown voltage rated between 600 – 900 V and maximum power loss of 40 W.

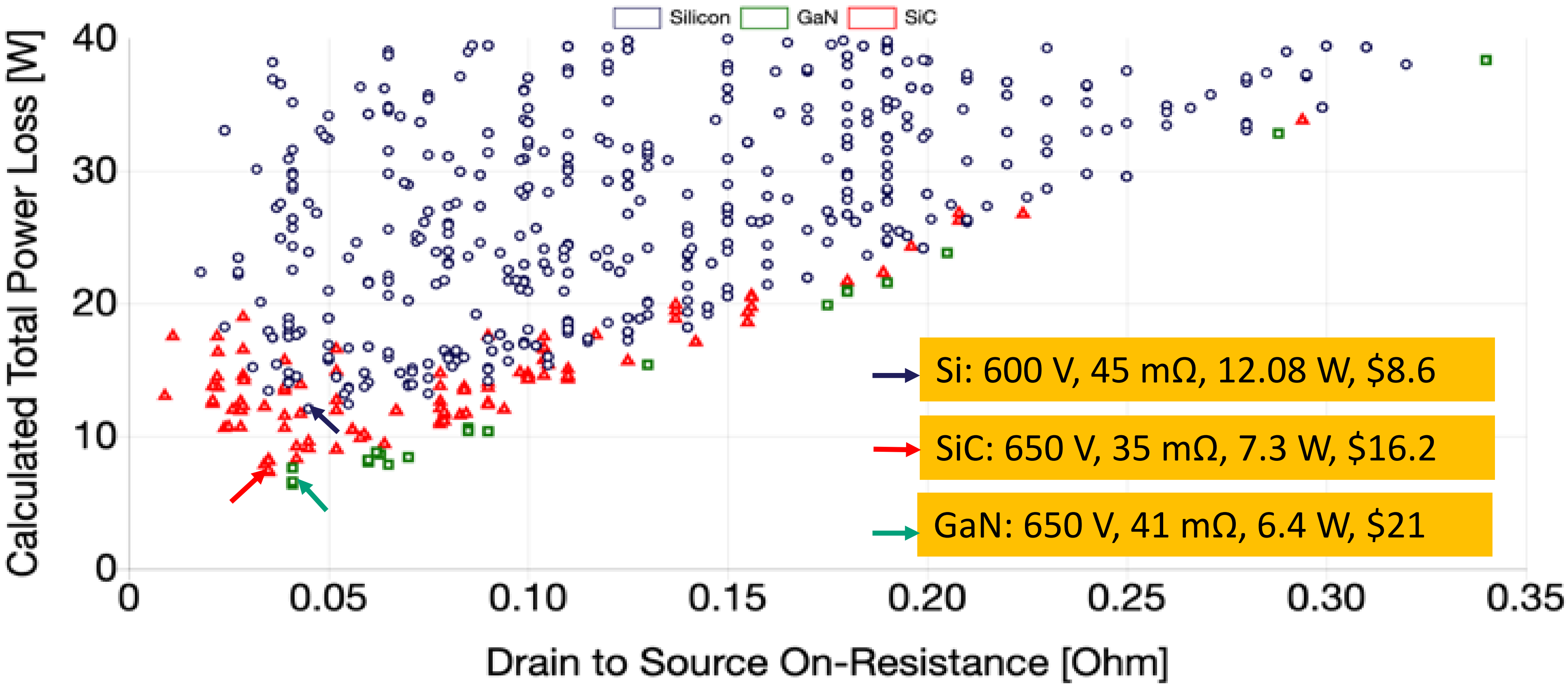
- For this power converter we consider power devices made of different materials - Si MOSFET, GaN HEMT and SiC FET. We then calculate the total power loss for each type of device using DiscoverEE's power loss dashboard and plot the total calculated power loss for the devices with respect to their maximum on-resistance, $R_{DS(ON)MAX}$



Operation at 400 V, 15 A, 1 kHz

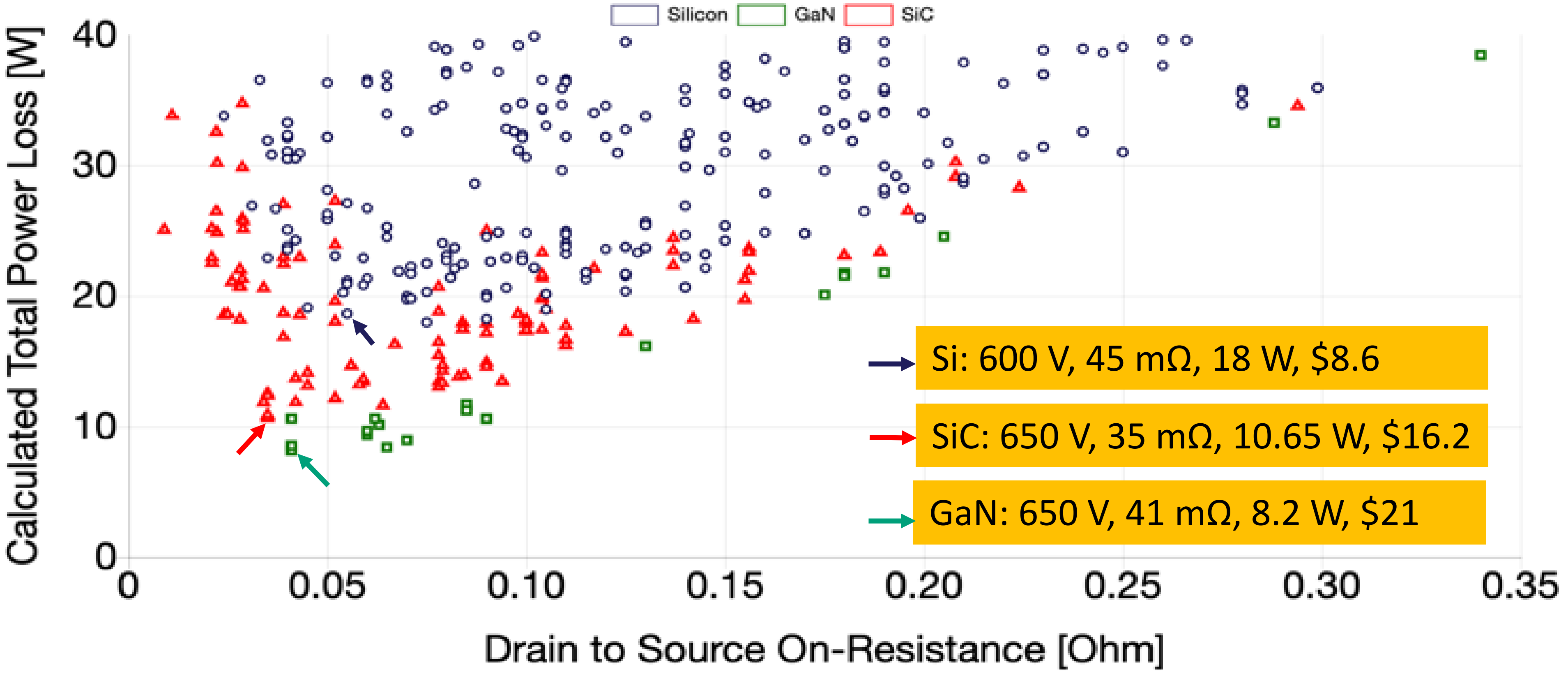
At 1 kHz operation, the lowest power losses among the available devices in the market today come from 650V, 9 mΩ SiC FET as it achieves the lowest on-resistance but at ~3.4 times the price of 600V, 18 mΩ Si device.

But we find that if the same power loss needs to be achieved Si device cost will only be slightly lower than that of SiC and GaN.



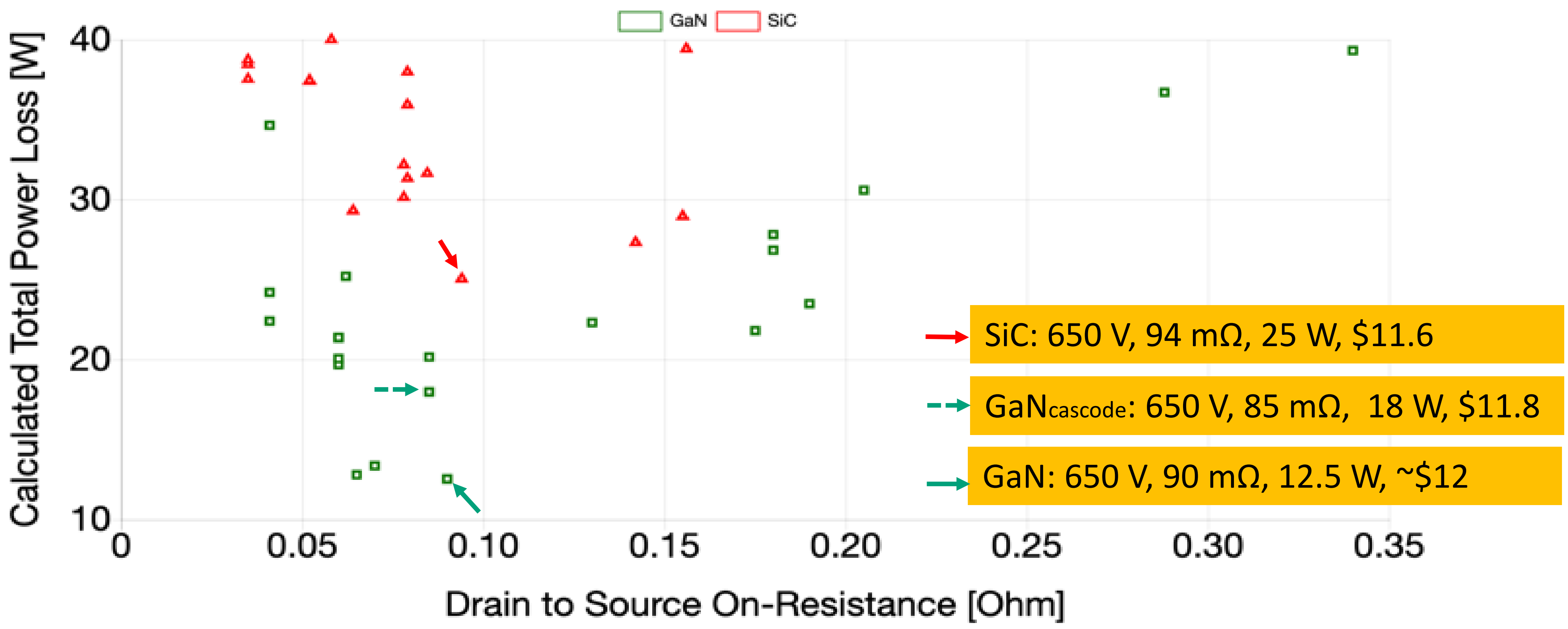
Operation at 400 V, 15 A, 10 kHz

At 10 kHz, lowest power losses come from GaN device as it achieves the combination of low on-resistance, gate charge and reverse recovery loss. The price of GaN device is 2.4 times that of Silicon device and achieves 53% of power loss. Here SiC device offer are a good alternative as it costs 1.88 times the Silicon device and achieves 60% of the power loss.



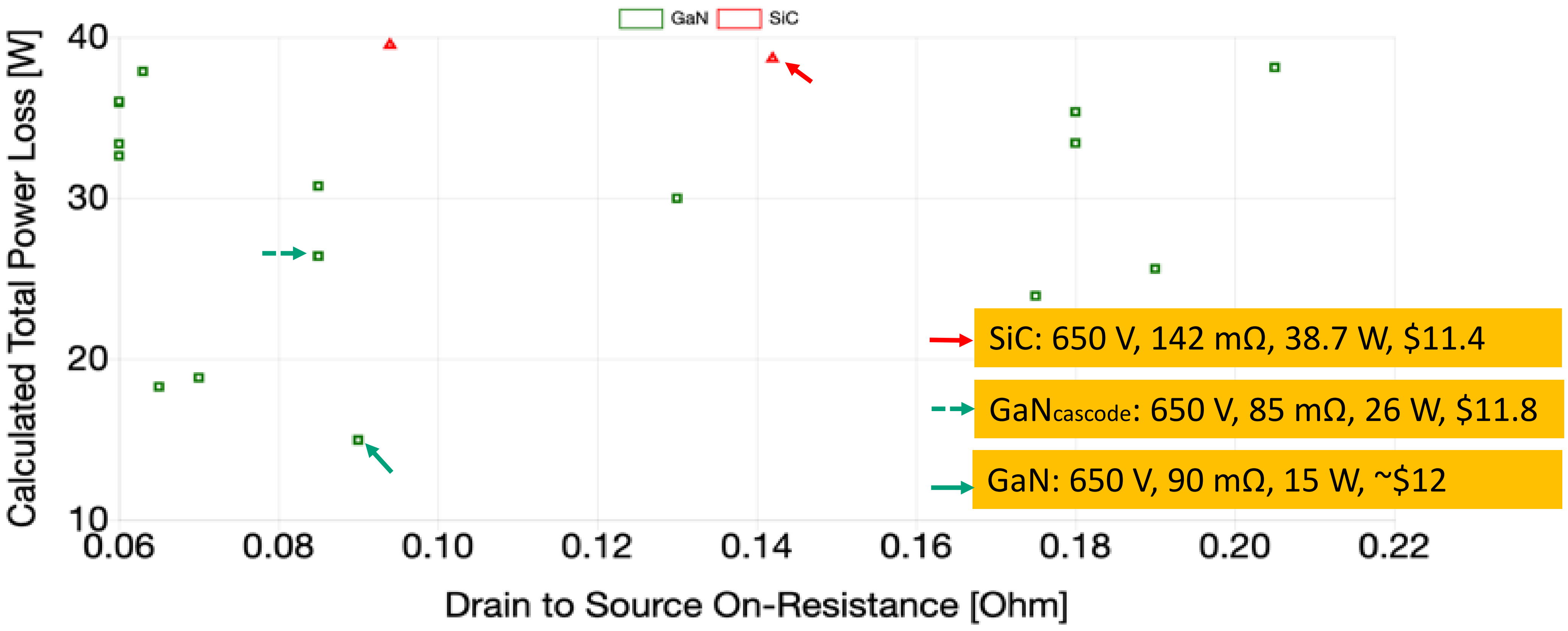
Operation at 400 V, 15 A, 20 kHz

At 20 kHz operation, the lowest power loss come from GaN device followed by SiC device. The overall dynamics of device selection do not change much except that the GaN device is slightly more compelling as it achieves 45% power loss of the Si device vs. 60% from SiC device.



Operation at 400 V, 15 A, 100 kHz

At 100 kHz operation, GaN device with the lowest power is 12.55W and comes from 650V, 90 mΩ device with price of ~$12. Cascode GaN device with the lowest power is 18W and comes from 650V, 85 mΩ device with price of $11.8. For SiC, the lowest power loss of 25 W comes from a 650V, 94 mΩ device with price of $11.6.



Operation at 400 V, 15 A, 200 kHz

At 200 kHz, SiC devices have high power loss and GaN devices appear to be only options for efficiently managing the thermals. We also observe that enhancement mode GaN devices are the best options for operating the power converter followed by the cascode configuration GaN devices.

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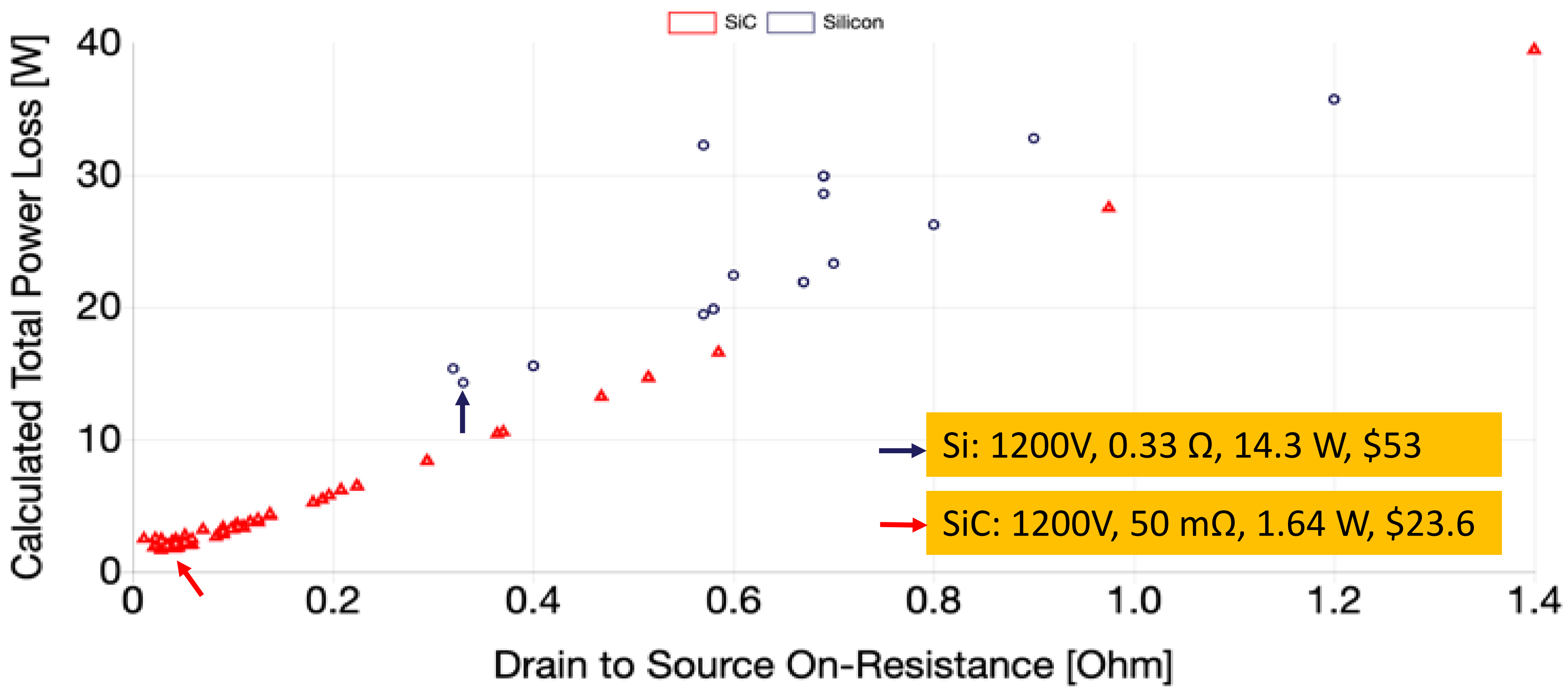
Results for Operation at 800 V, 7.5 A, D=0.5 from 1-200 kHz

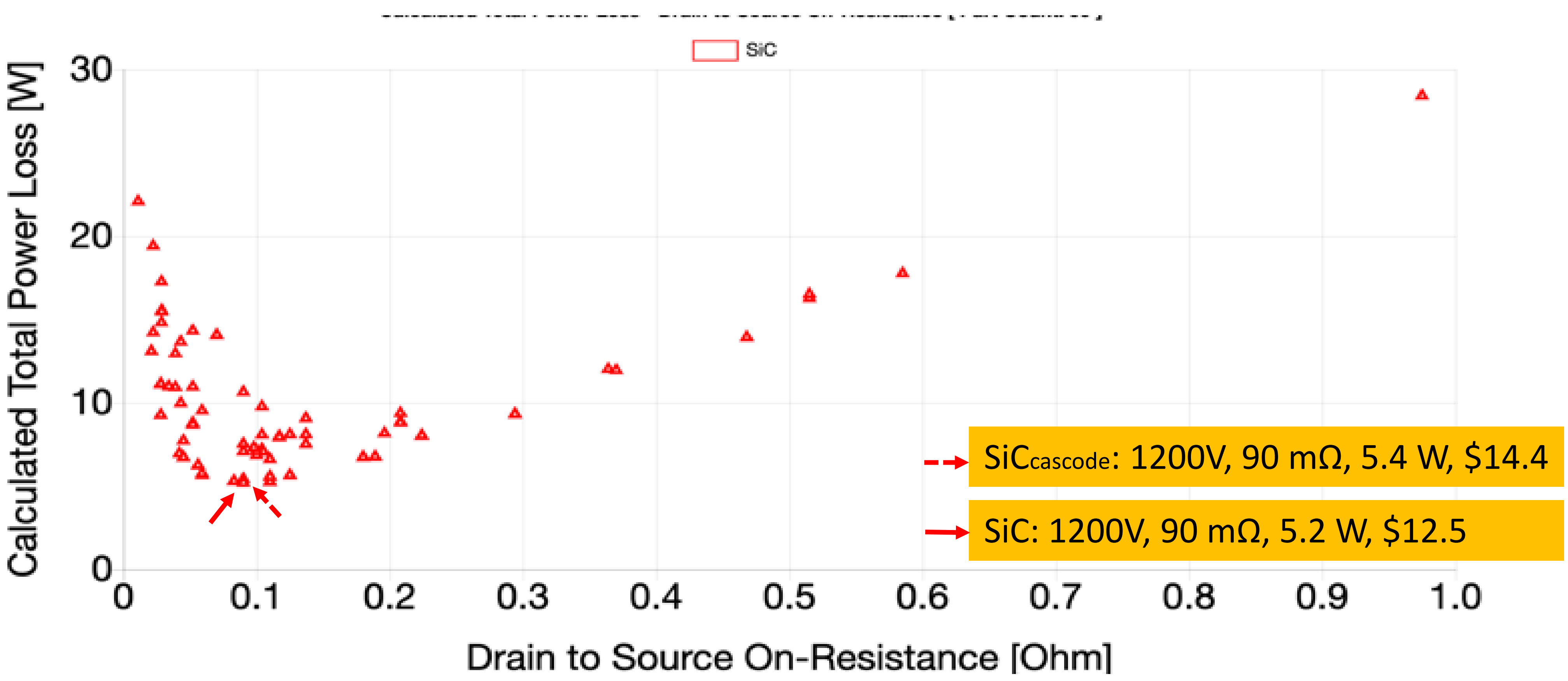
- For a hypothetical 3 kW power converter, consider the first set of operating conditions V_{DS} = 800 V, I_D = 7.5 A, D = 0.5, $R_{G\ Total}$ = 10 Ω, T_{AMB} = 25 °C and V_{GS} = 10 V at F_{SW} of 1 kHz, 10 kHz, 20 kHz, 100 kHz and 200 kHz with requirement of device breakdown voltage between 1100 – 1700 V and maximum power loss of 40 W.

- For this power converter we consider power devices made of different materials - Si MOSFET, GaN HEMT and SiC FET. We then calculate the total power loss for each type of device using DiscoverEE's power loss dashboard and plot the total calculated power loss for the devices with respect to their maximum on-resistance, $R_{DS(ON)MAX}$



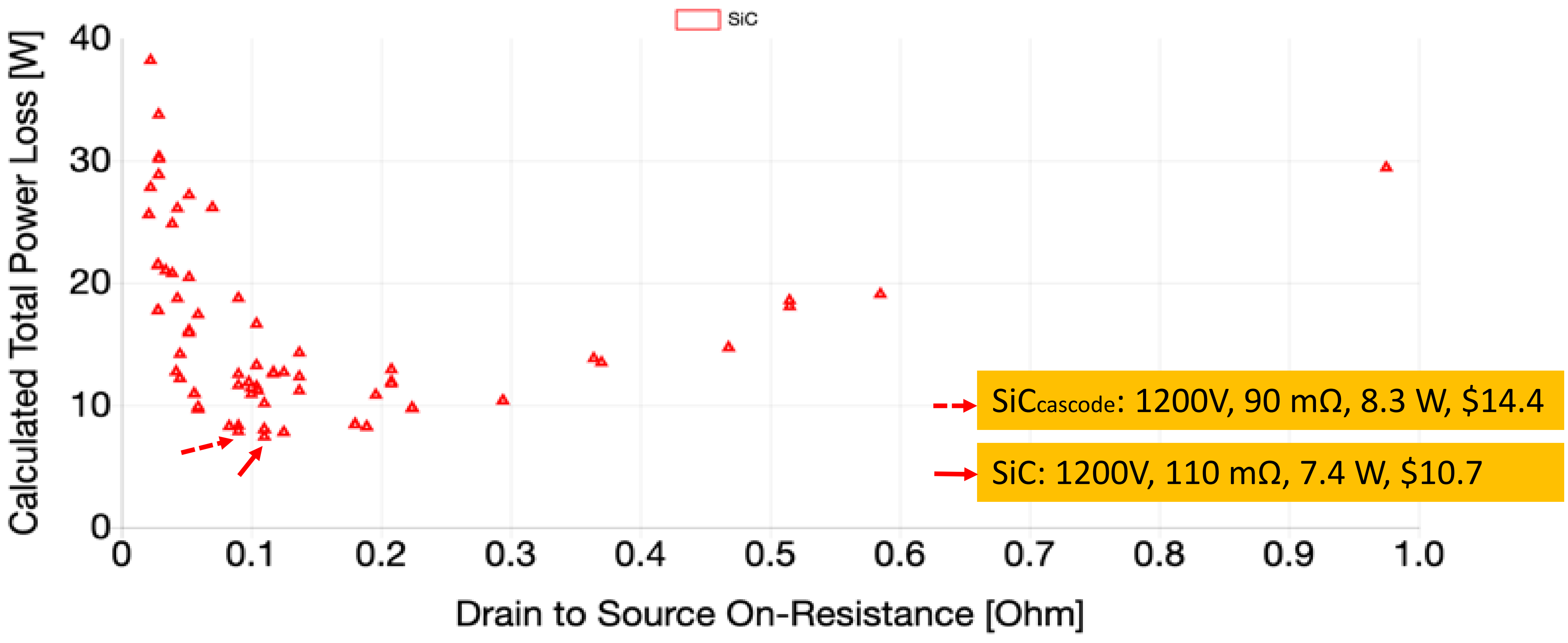
Operation at 800 V, 7.5 A, 1 kHz

For high voltage operation at 800 V, even at low switching frequency of 1 kHz, Si MOSFET devices are no match to SiC both in terms of achieving power loss performance and cost. Of course, there are other types of devices such as IGBTs which are more suitable for such operation we have restricted this study to FET devices only in this paper.



Operation at 800 V, 7.5 A, 10 kHz

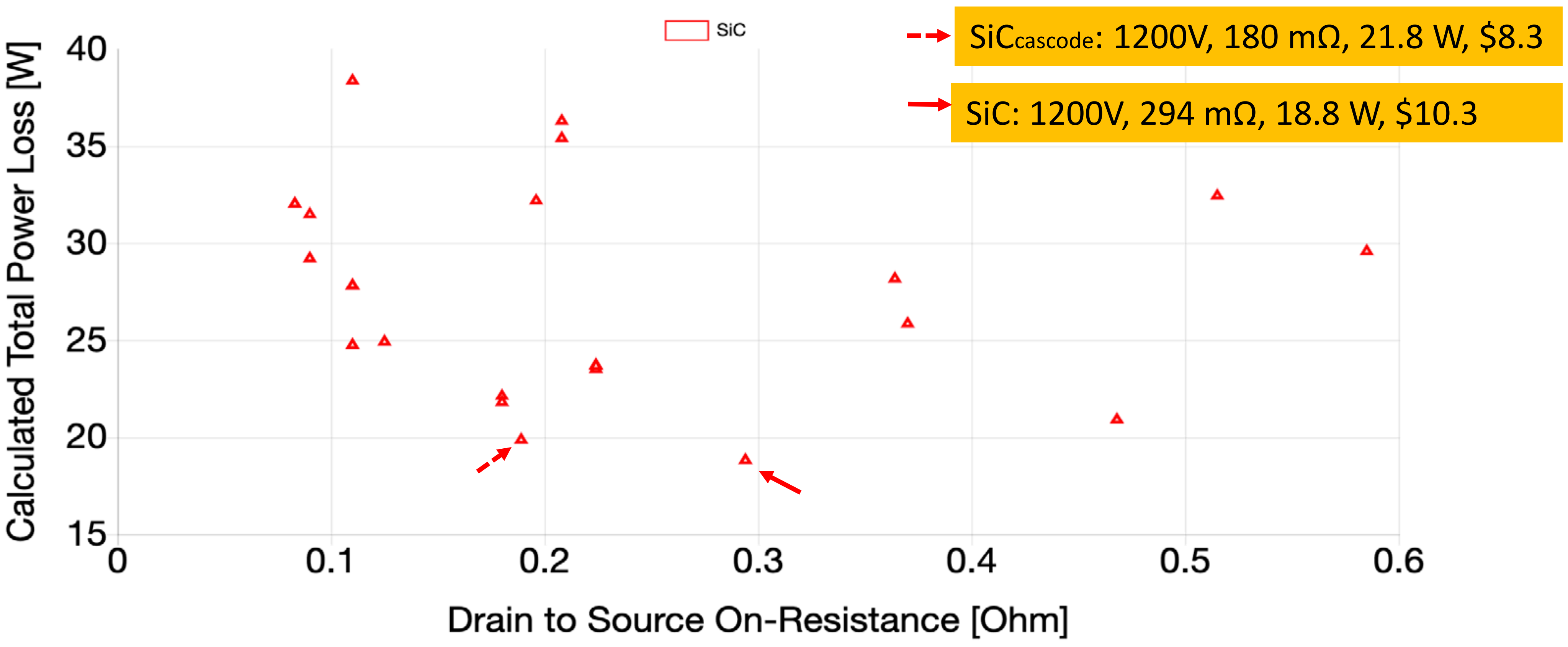
At 10 kHz operation, the lowest power losses come from 1200 V SiC devices with $R_{DS(ON)MAX}$ in the range of 90-110 mΩ. No Si or GaN devices meet our criteria.



Operation at 800 V, 7.5 A, 20 kHz

For SiC, the lowest power loss of 7.4 W is from 1200 V, 110 mΩ device in TO-247 package. Distributor price for 1 unit is $10.7.

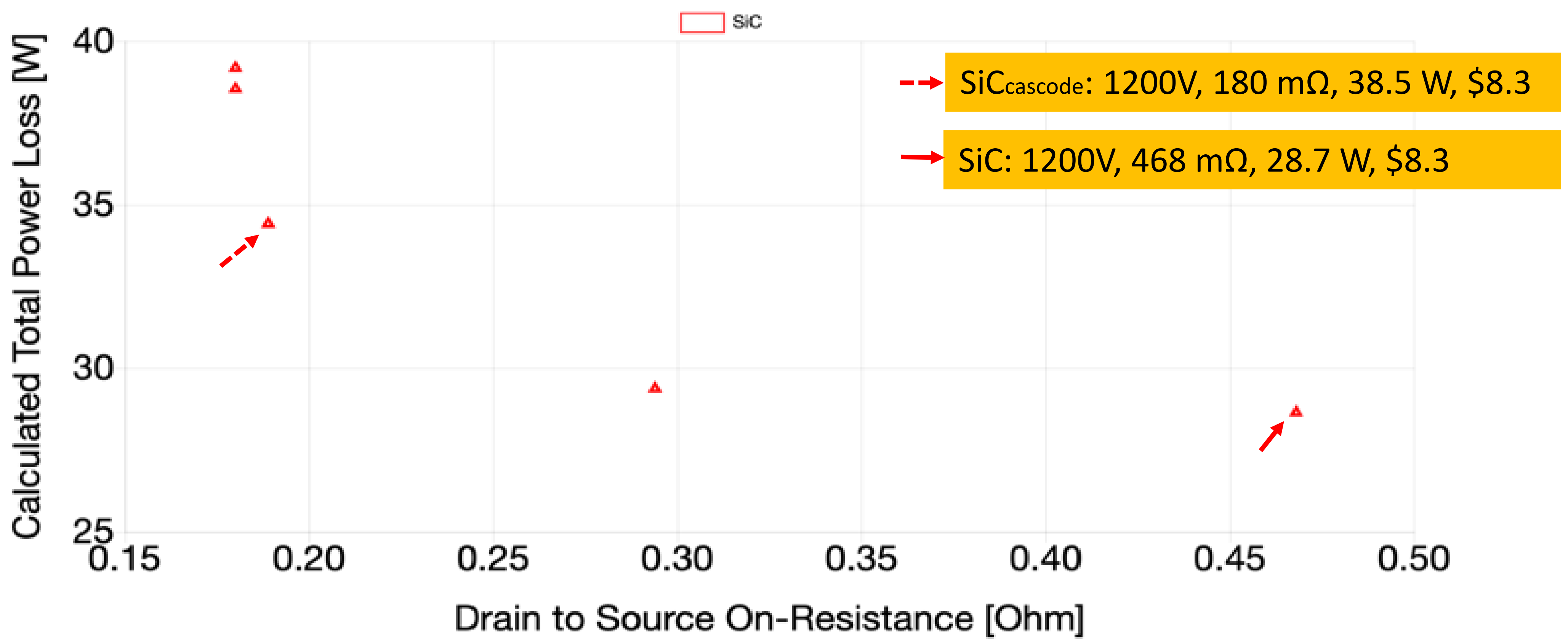
Among cascode configuration SiC devices, there is 1200 V, 90 mΩ device in TO-247 with very similar power loss of 8.3W. Price of 1 unit is $14.39.



Operation at 800 V, 7.5 A, 100 kHz

For SiC, the lowest power loss of 18.8 W is from 1200 V, 294 mΩ device in TO-247 package. Distributor price for 1 unit is $10.3.

Among SiC devices cascode configuration, there is 1200 V, 180 mΩ device in TO-247 with very similar power loss of 21.8 W. Price of 1 unit is $8.3.



Operation at 800 V, 7.5 A, 200 kHz

For 200 kHz operation, only a handful of 1200 V devices with $R_{DS(ON)MAX}$ in the range of 180-468 mΩ meet power loss criteria and lowest power loss achieved is 29.4 W. The lowest power loss of SiC devices with cascode configuration is 34% higher which can be reduced if the devices were to be optimized for this operating condition.

Summary

400 V, 15 A	1 kHz	10 kHz	20 kHz	100 kHz	200 kHz
Silicon	4.06 W, 600 V, 18 mΩ	12.08 W, 600 V, 45 mΩ	18 W, 600 V, 45 mΩ	-	-
	$18.73	$8.60	$8.60	-	-
Silicon Carbide	2.21 W, 650 V, 9 mΩ	7.3 W, 650 V, 35 mΩ	10.65 W, 650 V, 35 mΩ	25 W, 650 V, 94 mΩ	38.7 W, 650 V, 142 mΩ
	$64	$16.20	$16.20	$11.60	$11.40
Gallium Nitride	4.8 W, 650 V, 41 mΩ	6.4 W, 650 V, 41 mΩ	8.2 W, 650 V, 41 mΩ	12.55 W, 650 V, 90 mΩ	15 W, 650 V, 90 mΩ
	$18.9	$20.77	$20.77	~$12 est.	~$12 est.
800 V, 7.5 A	**1 kHz**	**10 kHz**	**20 kHz**	**100 kHz**	**200 kHz**
Silicon	14.29 W, 1200 V, 330 mΩ	-	-	-	-
	$88	-	-	-	-
Silicon Carbide	1.64 W, 1200 V, 50 mΩ	5.2 W, 1200 V, 90 mΩ	7.4 W, 1200 V, 110 mΩ	19 W, 1200 V, 294 mΩ	29 W, 1200 V, 468 mΩ
	$23.60	$12.50	$10.70	$10.30	$8.30
Gallium Nitride	-	-	-	-	-

Conclusion

Our study shows that the choice of device material for minimizing power loss depends on the operating conditions (V, I, f, D, Vgs, Rg etc.) as well as characteristics of the material and device.

For operation at 400 V / 15 A with devices rated at 600 – 900 V:

1kHz or lower: Si devices offer a very good performance for their price.

10-20kHz: GaN offers lowest power loss but SiC devices offer a good value at comparable losses

100-200kHz: GaN devices achieve the lowest power loss by a wide margin over SiC and Si devices.

For operation at 800 V / 7.5 A with devices rated at 1100 – 1700 V, SiC is the clear winner for achieving the lowest power loss for low as well as high frequency operation.

Power losses increase substantially with switching frequency and our study shows that:

At 20 kHz or lower, it is beneficial to operate the converter at higher voltage and use SiC devices.
At 100 kHz or higher, it is beneficial to operate the converter at lower voltage with GaN devices.

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Thank You

Thank you for your attention and I look forward to answering any questions you may have about our work.

At DiscoverEE, we value your opinion and feedback.

Please get in touch for further discussions.

Author: Shishir Rai

Website: www.discoveree.io | Email: rai@discoveree.io
Address: 100 Pine St., Ste. 1250, San Francisco, CA 94111

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