

NEXGEN[™]
POWER SYSTEMS

Re-inventing Power Electronics:
NexGen Power Systems with NexGen Vertical GaN[™]
Whitepaper

Table of Contents

Current Technology cannot meet market expectations	03
Gallium Nitride: The Perfect Wide bandgap material	04
NexGen Vertical GaN™: The perfect power semiconductor	05
Value Propositions of Vertical GaN	06
Low Losses and Highest Switching Frequencies	07
Robustness and Reliability	08
Re-inventing Power Electronics	10
Scalable, Software Configurable Power Supply Platform	11
Making a Global Impact	12

Introduction

Silicon Can't Keep Up with Today's Demands

When it comes to semiconductors, silicon has long reigned supreme. Silicon has been the material of choice to power the world's electronics for decades. This is especially true in power electronics. As power systems became smaller, so did silicon based MOSFETs (metal oxide semiconductor field effect transistors). As gadgets got smarter and more power-hungry, silicon chips increased in power density and efficiency.

The world—and our electronics—continue to evolve, and it's becoming clear that we have taken silicon as far as we could. We've begun to reach the theoretical limit on how much more silicon-based transistors can be improved.

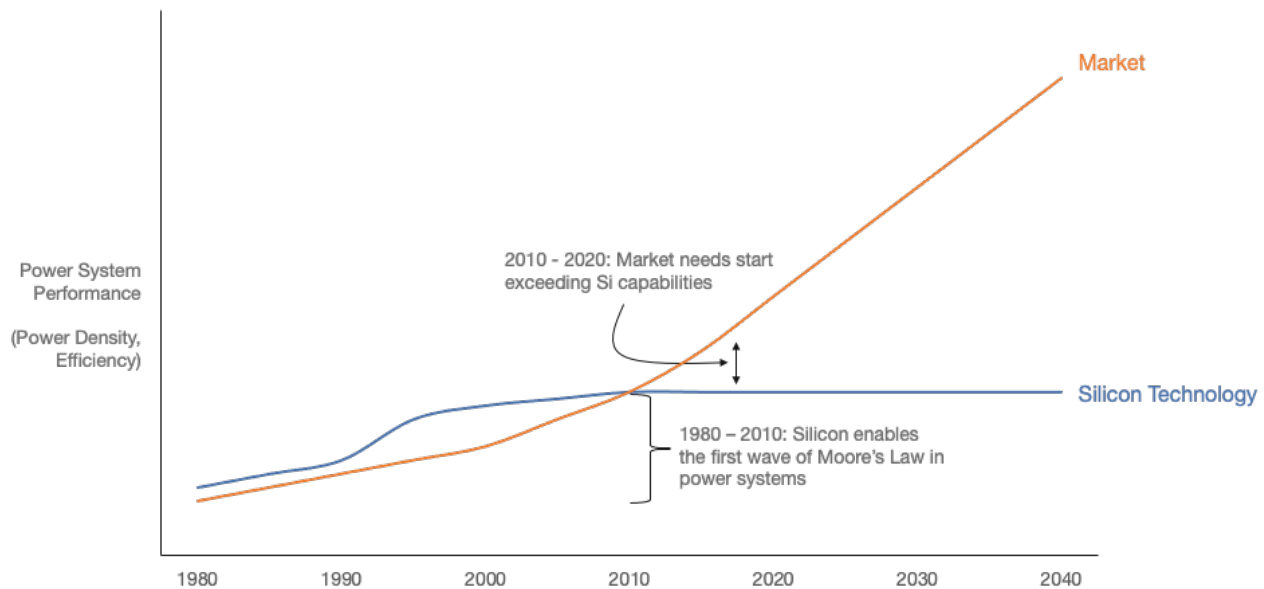


Fig 1: Silicon reigned supreme for the last 3 decades, but it simply has not been able to keep up

With digital transformation taking place across the globe, both businesses and consumers alike are demanding devices and systems with ever-increasing speed, performance, and energy efficiency. Because silicon can no longer keep up with those demands, the industry is turning to an innovative, more powerful contender.

Say Hello to Gallium Nitride

Gallium nitride (GaN) isn't new. It's been used to power blue LEDs (light-emitting diodes) since the 1990s. But today the power conversion industry is taking another look at the material and realizing it has great potential in a much wider range of power applications. To better understand how Gallium Nitride holds such promise, it is important to talk about the electronic bandgap.

Every material has an inherent electronic bandgap, and semiconductor materials have bandgaps that can be crossed only under certain conditions. Superior semiconductors have a wide electronic bandgap and are called wide bandgap materials.

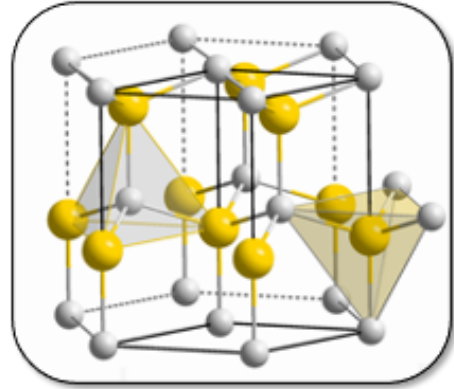


Fig 2: GaN Crystal

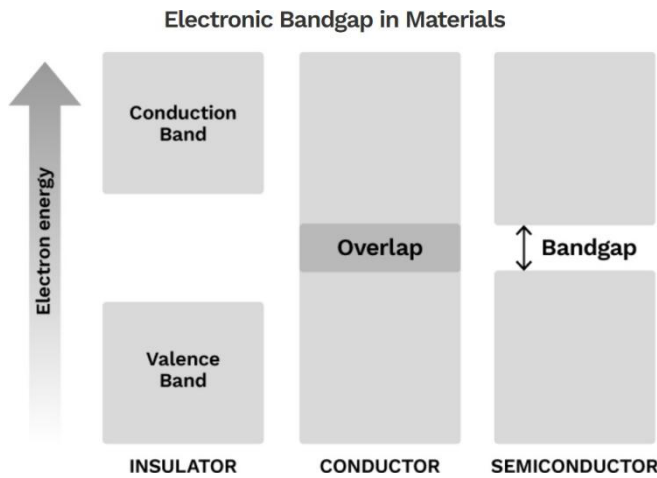


Figure 2. A diagram of electronic bandgap in a variety of materials.

GaN is inherently better

Wide bandgap materials have inherently superior semiconductor properties. GaN has the widest bandgap of any commercially utilizable material. This makes GaN the ideal choice for a power semiconductor.

SEMICONDUCTOR MATERIALS		
MATERIAL	CHEMICAL SYMBOL	BANDGAP ENERGY (EV)
Germanium	Ge	0.7
Silicon	Si	1.1
Gallium Arsenide	GaAs	1.4
Silicon Carbide	SiC	3.3
Zinc Oxide	ZnO	3.4
Gallium Nitride	GaN	3.4

Figure 3. GaN has the widest bandgap, which makes it a superior semiconductor material

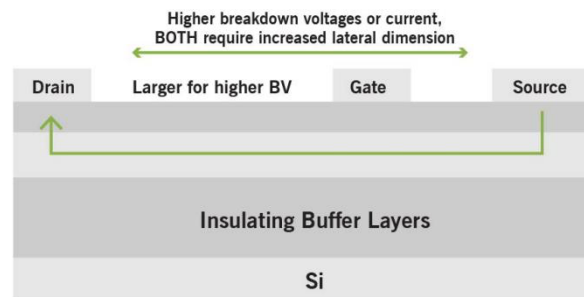
In addition to this, the Baliga Figure of Merit (BFOM), which couples mobility to critical electric field, is a key metric of vertical device performance. BFOM relates the specific on-state resistance and breakdown voltage for a given material system with the mobility and electric field. GaN scores much higher in this metric compared to Si and SiC devices.

Parameter	Si	SiC	GaN	units
Relative permittivity, ϵ	11.7	9.7	10.4	
Electron mobility, μ_n	1200	500	1000	cm ² /V-sec
Critical field, E_c	3x10 ⁵	2.4x10 ⁶	3.4x10 ⁶	V/cm
BFOM (relative to Si)	1	177	1080	

Table 1: GaN has the best Figure-of-Merit, much superior than other semiconductor material.

Only GaN-on-GaN Unlocks the Full Potential

Device Area →	GaN	GaN	GaN
Carrier Wafer →	Si	SiC	GaN
Attribute	GaN-on-Si	GaN-on-SiC	GaN-on-GaN
Defect Density [cm ⁻²]	10 ⁹	5x10 ⁸	10 ³ x10 ⁶
Lattice Mismatch [%]	17	3.5	0
CTE Mismatch [%]	54	25	0
Layer Thickness [μm]	1-2	2-6	>40
Reliability	Low	Low	High
Device Types	Lateral	Lateral	Vertical & Lateral



GaN power transistors can be created via epitaxially grown GaN layers on different types of carrier wafers. There are significant impacts in the choice of substrate material in terms of realizing the full potential GaN's superior material properties. When compared against other substrate material, by maintaining a GaN-only structure via homoepitaxy, GaN-on-GaN power semiconductors offer the superior approach for fabricating vertical power devices. The NexGen Vertical GaN™ technology is based on growing GaN on GaN wafers as compared to other available options, as shown in the table below.

Figure 4. (Left) Impact of epitaxial GaN growth on various carrier wafers (Right) Growing GaN on a different carrier material requires adding additional insulating buffer layer

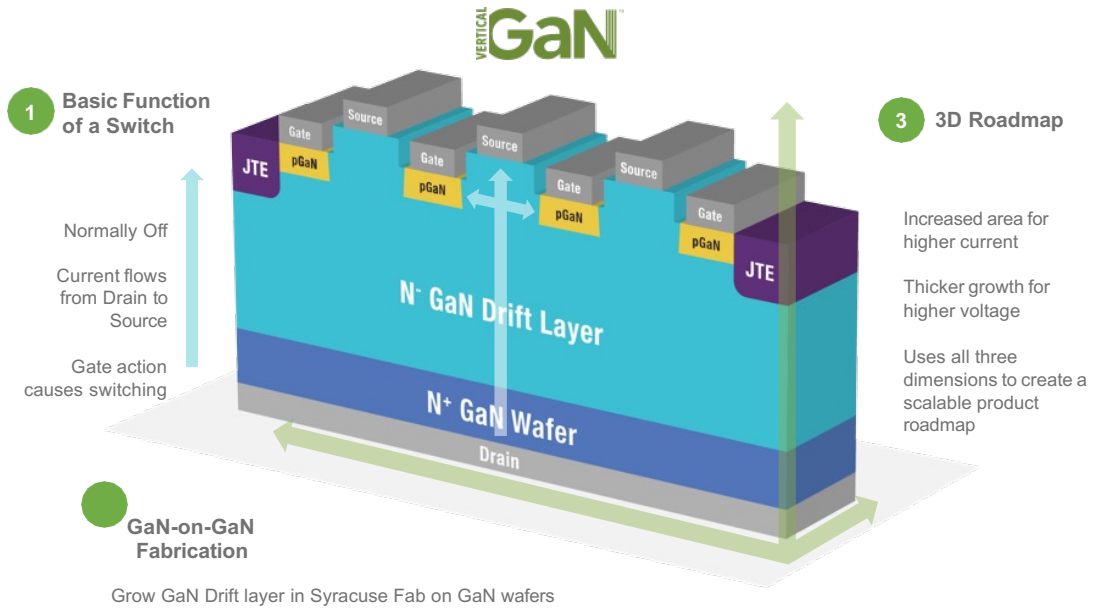


Figure 5. NexGen Vertical GaN™

The NexGen Vertical GaN™ is the world’s first commercially available GaN-on-GaN technology which unlocks the full potential of this ideal power semiconductor material with the following advantages:

- A normally-off, enhancement-mode junction field-effect transistor (JFET)
- Reduced defect density in the GaN-on-GaN homoepitaxial layers
- Superior breakdown voltage (BV) and current capability for a given chip area than any other GaN device
- Only GaN technology that can deliver breakdown voltage of up to 4kV
- Reduced dynamic on-resistance changes due to less reliance on surface passivation
- Smallest size compared to other power semiconductors for a given current rating

Let’s dig a little deeper into each of these fundamental value propositions.

1) **Smallest Size**

By utilizing the full three dimensions of the GaN-on-GaN structure, Vertical GaN devices can scale to higher current devices by increasing the area and higher voltage devices by increase the thickness of the GaN epitaxial region. NexGen’s Vertical GaN power semiconductors are 95% smaller than silicon, and 4-6x smaller than other wide bandgap power semiconductor technologies.

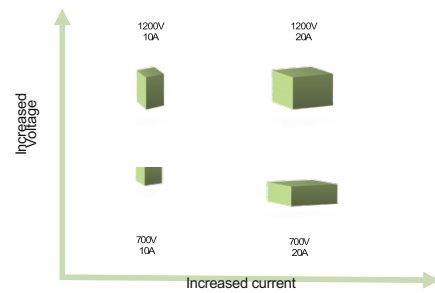
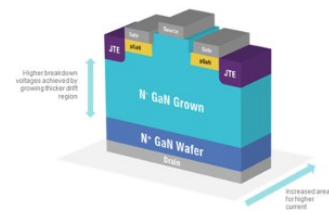


Figure 6. NexGen Vertical GaN utilizes the full 3D structure of GaN-on-GaN



2) Lowest Capacitance and Lowest Switching Losses

Capacitance is a measure of a system’s ability to store an electric charge. It’s directly related to the volume of the device, so the smaller the device, the lower the capacitance. The lower the capacitance, the greater the switching frequency. With Vertical GaN’s size advantage, it offers nearly 50% better switching figure of merit for hard-switching and soft-switching, two key metrics to determine the efficiency of the switching operations.

Additionally, there is no body diode between the drain and the source of a Vertical GaN device, resulting in zero reverse recovery charge. This means that the switching cycle does not have to wait for the reverse recovery charge to be removed from the body diode junction.

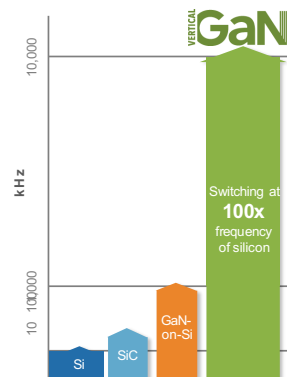
	Coss	Co(tr)	FOM Soft SW	Co(er)	FOM Hard SW	R _{DSon} at 150°C
NexGen 170mΩ	12pF	21.9pF	5900	16.6	4500	270mΩ
120mΩ SiC (Scaled)	32pF	56pF	13400	40	9600	240mΩ
Vertical GaN vs SiC	0.38	0.39	0.44	0.42	0.47	1.13

Table 2: Vertical GaN has the best soft switching and hard switching figure of merit

3) Highest Switching Frequency

Low capacitance and lower switching losses enable power systems engineers to switch the power semiconductor at the highest switching frequency possible. The inherent properties of NexGen Vertical GaN™ enable switching up to 10MHz. This is nearly 100x better than Silicon. The high switching frequency enabled by Vertical GaN results in more precise waveform generation for superior performance.

Figure 6. Vertical GaN provides the highest switching frequency



4) No current collapse a.k.a dynamically increased resistance

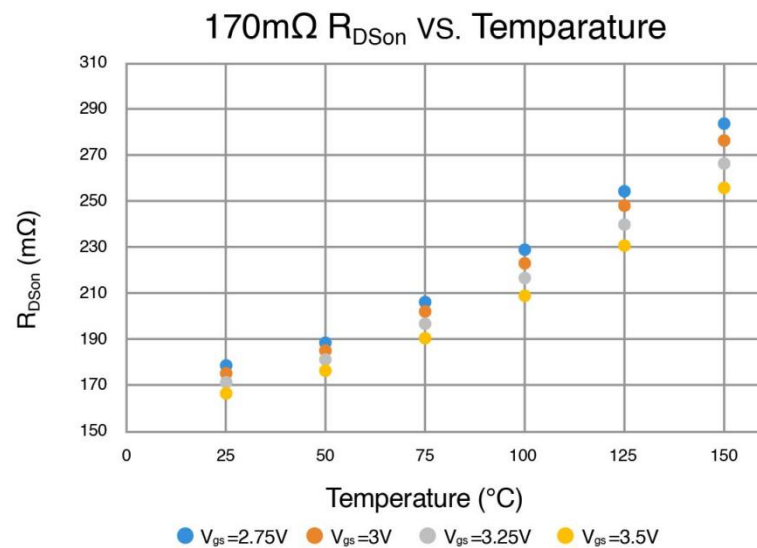
When GaN is grown on other carrier materials, for example the GaN-on-Si, the device relies on sheet of electron charge due to polarization at the interface between the insulating buffer layers and the GaN conducting material. This polarization charge is highly sensitive to traps in the conducting material, the passivation interface, and the buffer layers below the channel. These traps can get charged and discharged due to gate bias and impacts the 2DEG to increase the resistance dynamically, leading to reduced current or current collapse. Power Systems designers work around this dynamically increasing resistance by starting their designs with a smaller resistance to begin with, which is increased size, lower capacitance, and lower switching frequency, leading to a sub-optimal power system design.

NexGen Vertical GaN does not suffer this current collapse as the device does not have any of the traps, passivation interface, or insulating buffer layers since the conducting material (GaN) is homoepitaxially grown on the carrier material (GaN)

5) Best-in-class temperature coefficient

Power Systems designers have to worry about the operation of the power semiconductor at 150°C since this is the normal operating point of the electronics inside every power system. The relatively deep layer of dopant in the drift layer of NexGen Vertical GaN increases ionized impurities over temperature offsetting the degradation of mobility with temperature. This results in Vertical GaN devices having a temperature coefficient of 1.6 vs. 2.3 for HEMT and 2.25 for Si devices. This means that a typical 70mΩ Vertical GaN device will require a 50mΩ HEMT device for the same application. This is equivalent to paying an additional area penalty of 25% over the 250% higher area of a HEMT device compared to the Vertical GaN devices.

Figure 7. Vertical GaN provides the best-in-class temperature coefficient.



6) Avalanche Robust

An Avalanche event in a semiconductor is a form of electric current multiplication that can allow very large currents within materials which are otherwise good insulators. When a power semiconductor device exceeds the breakdown voltage, the resulting electric field becomes strong enough to create additional carriers. In this case, free carriers collide with and dislodge carriers from the lattice. These newly dislodged carriers create new additional free carriers and an immediate increase in free carriers, resulting in avalanche breakdown. In other GaN technologies, like the GaN-on-Si HEMT, the leakage gradually increases through sub-surface conduction and, thus, avalanche behavior is not realized. This results in power system engineers having to put expensive clamping circuits to ensure the power semiconductor behaves appropriately under unexpected voltage fluctuations.

Unlike GaN-on-Si, the NexGen Vertical GaN™ has a P-N junction and this enables the device to show both single and repeated cycle avalanche robustness. It allows reverse biased voltage to exceed the maximum breakdown voltage value for a specified energy and current limitations. This means that when faced with a situation where the system voltage exceeds the breakdown voltage of the device,

the Vertical GaN power semiconductor avalanches circuits don't require external voltage clamping components. NexGen has seen the 1200V rated Vertical GaN device consistently avalanches at 1400V.

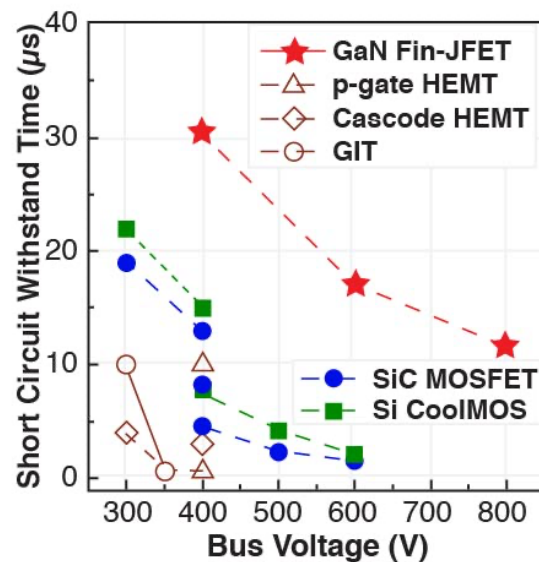
Table 3: Vertical GaN avalanche robustness

Parameters	SiC JFET	NEXGEN GaN FinFET
Blocking Voltage (V)	1200	> 800
Active Area (mm ²)	7	0.14
Testing condition	25 s, repetitive	3 s, repetitive
Critical E _{AVA} (mJ)	621	7~10
Normalized E _{AVA} (mJ/mm ²)	88.7	71.4
Avalanche cycle numbers survived	180	5000 (best)

7) The Ultimate Robustness Test: Short-Circuit Protection

A short circuit (SC) test is a widely used criteria for power device. 10 μs is the usual minimal time that most over-voltage protection circuits can step in to protect (e.g., commercial gate driver for HV Si IGBT). Hence, it is desired that the power semiconductor device has the capability to withstand 10 μs SC under the same bus voltage for device switching. So far, no wide band gap material has ever demonstrated this capability and the only semiconductor device is a Silicon based IGBT that shows >10 μs SC. SiC is generally believed to be not able to meet this standard unless adopting special designs (which compromise the device performance under normal operation). All Ga N commercial HEMTs cannot withstand >10 μs SC at a bus voltage higher than 300 V; this fundamentally limits their applications in EV powertrain applications (current 400 V bus voltage, future 800 V bus voltage). Only NexGen Vertical GaN™ has demonstrated >10μs SC capability at voltages exceeding its breakdown voltage.

Figure 8. Vertical GaN is the only device with >10μs short-circuit robustness



These key value propositions make the

NexGen Vertical GaN a perfect power semiconductor for the future. And, NexGen Power System is re-inventing power electronics by utilizing this revolutionary technology and not only manufacturing it in its own dedicated GaN-on-GaN fabrication facility, but also creating complete power systems that fully utilizes the capabilities of this technology.

In the early 20th century, transportation was going through a fundamental revolution, similar to what Power Electronics is facing today. Development of a motor engine was poised to revolutionize the way human beings moved across the globe. However, it was essential that the carriage that housed this motor and enabled this transportation revolution, also change. After all, one cannot put a 2000cc engine on a horse carriage and expect it to move like a Ferrari.

Reinventing Power Electronics



Figure 9. NexGen Power Systems: Re-inventing Power Electronics

NexGen is re-inventing power electronics just like the world of transportation was changed completely by the introduction of automobiles. With Vertical GaN, NexGen has created a perfect power semiconductor. To fully utilize this power platform, NexGen is also creating a platform to build power systems that scale across all wattage ranges across the entire market and make and sell complete power systems that leverage this platform.

In addition to having Vertical GaN at the core, the NexGen power platform brings fundamental innovation in power management algorithms that enable Vertical GaN to achieve the highest switching frequency possible. These novel, scalable, and software-configurable power algorithms ensure that the power platform can scale across different wattages and address the entire gamut of the power electronics market.

Furthermore, the NexGen power platform also incorporates the latest innovation in magnetics and thermal management to provide significant value across the entire power electronics value chain.

NexGen's Power Platform: Software & System Architecture built on Vertical GaN™

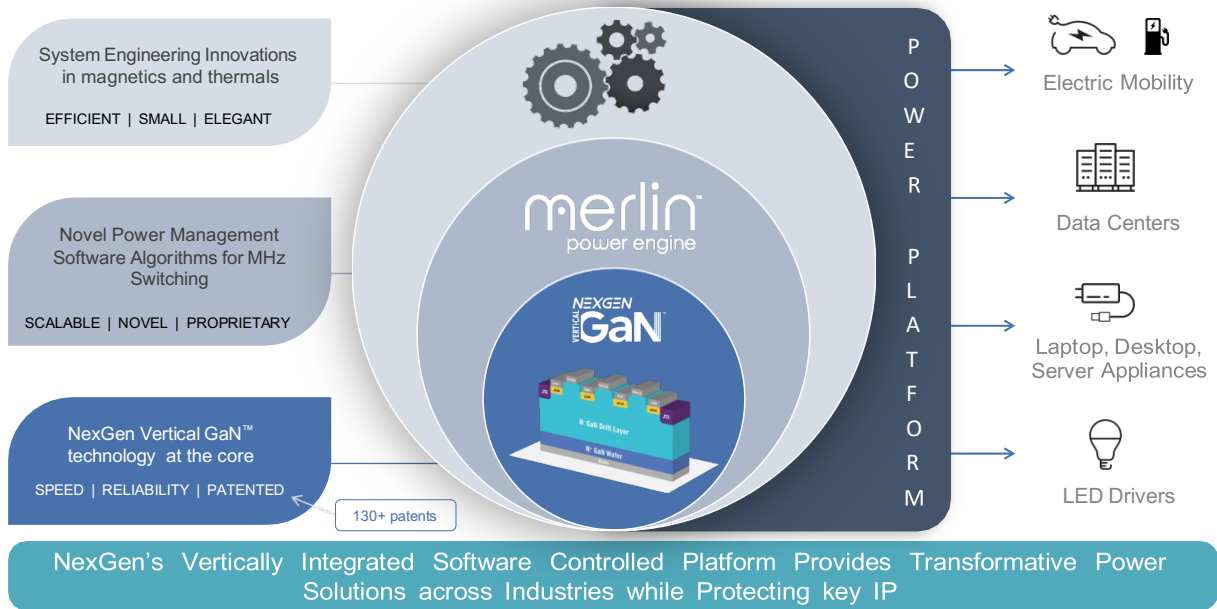


Figure 10. The NexGen Power Platform

The World's Smallest and Most Efficient Power Supply: NexSys 240W

Figure 11. NexSys 240W by NexGen: A 240W Power System with the NexGen Power Platform

An example of this power platform strategy in action is the NexSys 240W, the world's smallest and most efficient power system unit for the high-end computing market (e.g., gaming laptops). It utilizes all the key elements of the NexGen power platform and creates a system that is

- 61% smaller than typical power supplies in the same class
- 45% lighter than the best in class power supply
- Cuts power losses down by 50%

Above all, it provides users the experience they always crave for these power systems. Small, lightweight, portable, along with being robust, reliable, and efficient. This not-only meets but over the course of the next decade far exceed market expectations. For the world of power supplies for laptops, this would be equivalent of having the entire power supply fit into the AC plug.

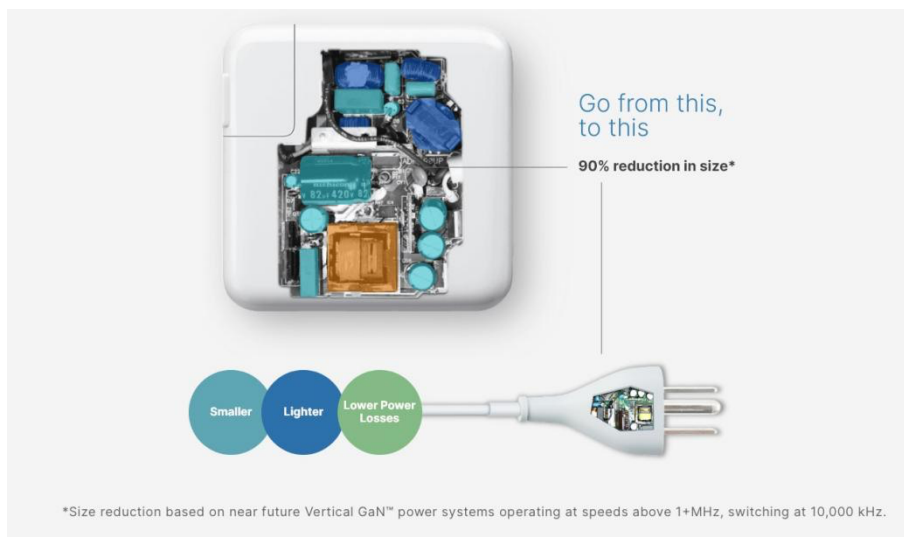
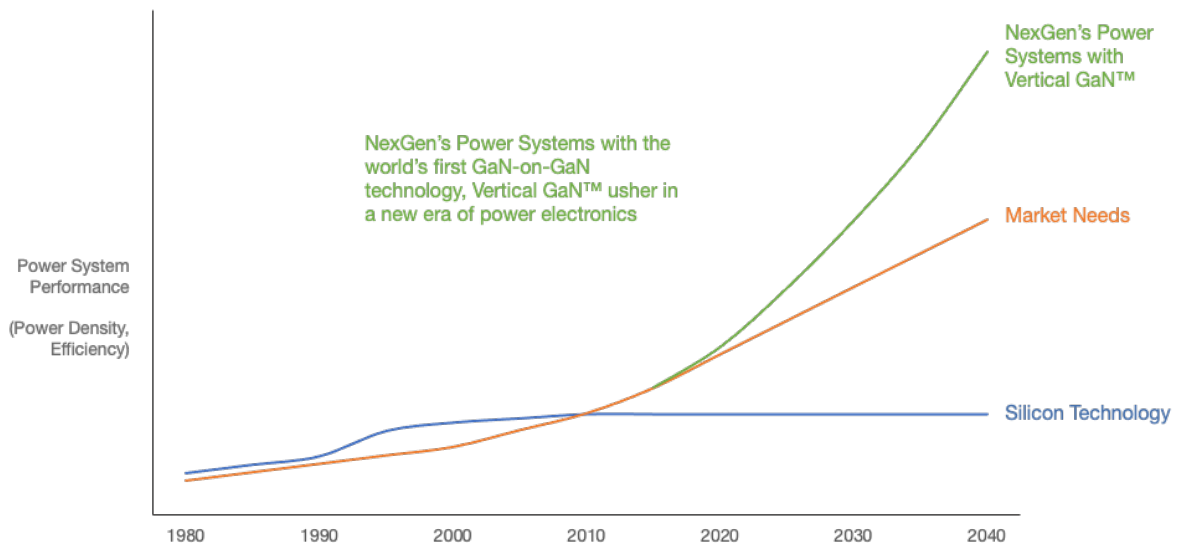
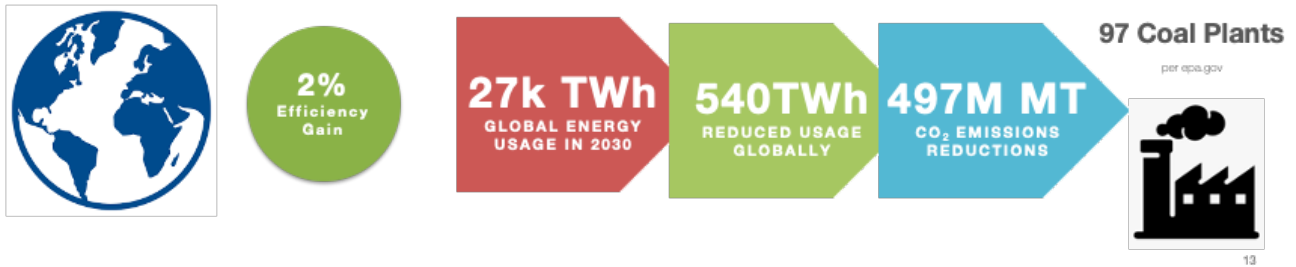


Figure 12. (Top) NexGen's Power Systems far exceeding market expectations (left) The vision of a smaller, lighter, more efficient power system

The Global Impact

The impact of improved power systems for the planet are significant. A simple 2% efficiency gain in power systems all across the world can present an opportunity to reduce CO2 emissions from the planet equivalent to ones generated by 97 coal fired power plants.



About NexGen Power Systems

NexGen Power Systems, the premier vertically integrated power electronics company, designs, develops, and manufactures innovative power conversion systems with its revolutionary NexGen Vertical GaN™ semiconductor technology.

Founded in 2017, NexGen Power Systems is revolutionizing power electronics with technology solutions utilizing GaN-on-GaN (NexGen Vertical GaN™) discrete semiconductor devices, controllers, modules, and systems that increase efficiency and reliability of power conversion systems while dramatically reducing their cost, size, and weight. Our vision is to create the smallest, lightest, most cost-effective power conversion systems in the world.



www.nexgenpowersystems.com

Published by
 NexGen Power Systems
 3151 Jay St #201, Santa Clara, CA 95054,
 United States