Silicon Superjunction MOSFET Technology – "The Overlooked Solution"

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Introduction

IceMOS Technology Corporation supplies high voltage, silicon based, Superjunction Power MOSFETs ranging from 600V to 750V. Devices in the current Gen-1 and Gen-2 portfolio offer a path to greater data center efficiency when used in electrical power management systems. As industry trends continue to push for data centers to do more to meet the ever increasing demand, there is also a challenge to reduce operating costs, increased up-time, perform with greater efficiency, and be more environmentally friendly.

This paper covers where and how silicon based Superjunction MOSFETs are used in data center power management today. It also highlights the vision for advancements being pursued by IceMOS for future use in data centers to help enable greater efficiencies and have a broader impact from using those products.

"And The Survey Says…"

The Uptime Institute's "Global Data Center 2022 Survey" [1] had 830 end user participants from a range of industries around the world. These IT and data center professionals gave their insight into a wide range of topics with their responses. As expected, the survey confirmed the respondent's belief in the predicted continuation of the industry's dynamic growth and increasingly explosive demands fueled by expanding technology driven applications and trends. The internet of things (IoT), artificial intelligence (AI), machine learning (ML), and Covid driven virtual experiences that remains today (online shopping, virtual meetings, conferences, and medical appointments) continue to feed industry growth. However, there were some unexpected responses to survey questions on topics related to data center sustainability, outages, and efficiency improvements that were of particular interest because they have a common denominator. "The use and management of electrical power".

The participants were not required to answer every question in the survey. Therefore, the number of responses may vary from question to question. Here is a summary of the responses to the above mentioned topics.

Sustainability – Even with legislation and in some cases published corporate targets, the survey concludes that of the 603 respondents there did not seem to be great deal of tracking and reporting in most of the categories listed in this question. As FIGURE 1 shows, the two categories most monitored are those related to power. This could be explained by the fact that utility costs for a data center can represent as much as 80% of the total operation expenses. Monitoring and reporting on the power usage is possibly viewed more as a business metric than a sustainability metric for many managers.

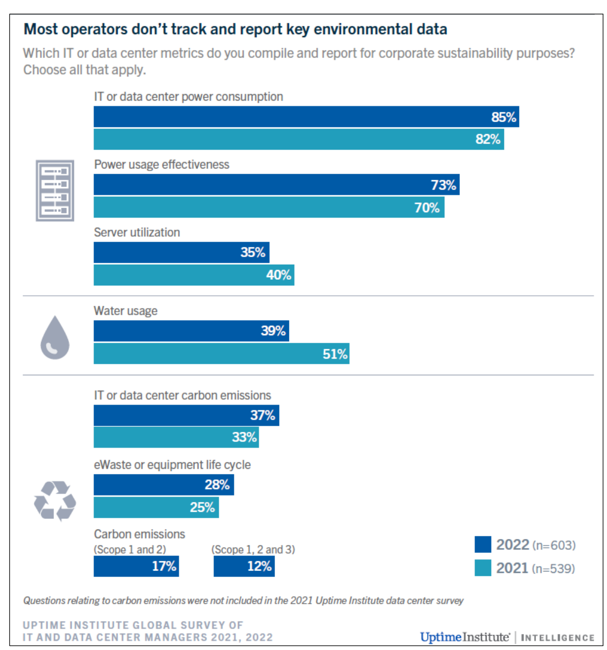

FIGURE 1: Environmental tracking responses

Outages – While there is good news that the number of disruptive outages reported by respondents dropped year on year from 69% in 2021 to 60% in 2022. It was not all good news on the topic of outages. Although fewer in number, the cost of those outages increased. Twenty-five percent of the 779 respondents said their most recent outage cost more than

$1 million in both direct and indirect costs (up from 15% in 2021 and 16% in 2020). The majority of the respondents, 45%, estimated the cost to be between $100,000 and $1 million. Changes in business and cost models were seen as factors that when disrupted, immediately translated into lost revenue.

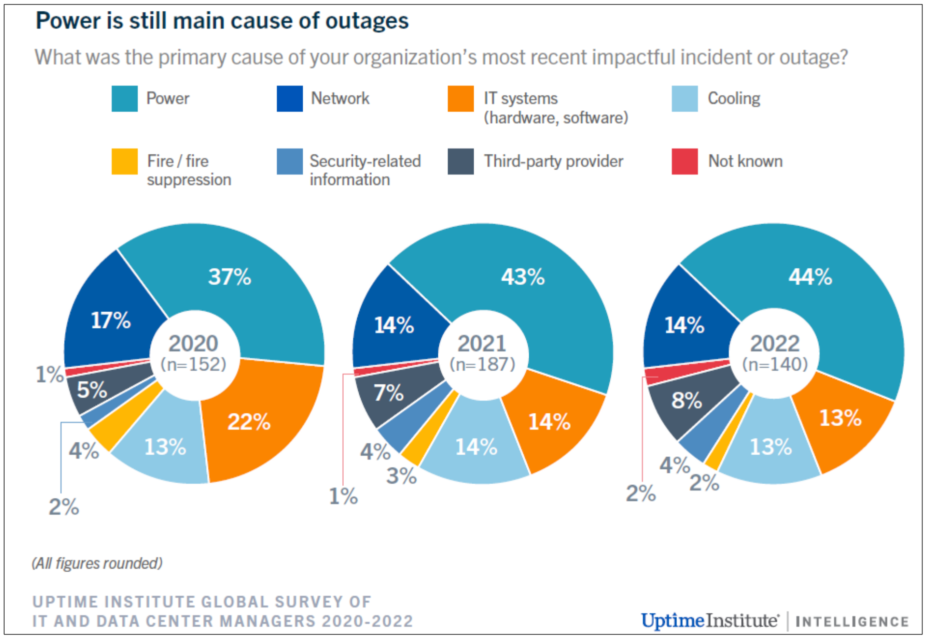

FIGURE 2: Causes of power outages responses

The second bit of bad news on the topic of outages, was that the primary cause of these outages has not changed. The Uptime researchers dug deeper in a separate analysis to identifies the main culprits causing the power-related outages. Their findings revealed that uninterruptible power supply failures, followed less commonly by transfer switch (generator/grid), and generator failures were the top three causes. As a rule, the Uptime researchers never attribute utility grid failures as a primary cause of outages. However, it was pointed out that the uptick seen in recent years for power-related failures may correlate directly to the aging grid infrastructure reliability issue that exposes data centers with substandard maintenance and training practices.

Efficiency Improvements – Participants were asked to provide their top three answers to the question of future innovations impacting data center efficiency in the next five years. Fifty percent of the 744 respondents to this question choose software-defined power as being the innovation they believed had the most promise of delivering significant improvements in energy efficiency over that period of time. The second and third highest selections were artificial intelligence (AI) for data center operations and the development of multisite resiliency as an alternative to equipment redundancy.

It is interesting to note that the top two efficiency solutions are software based solutions that depend on interaction with, and in some cases control of, the electrical systems to perform tasks such as load shedding, load balancing, or server throttling.

The IceMOS Technology mSJMOS™ Story

Semiconductors will undoubtedly play a key role in meeting the sustainability, outages, and efficiency improvements challenges identified in that Uptime survey for data center operators. Software innovations cannot be seen as a viable potential solution unless there are advances in the semiconductor chipset used on the hardware side. There is great emphasis, and rightfully so, being place on optimizing the performance capabilities of processing devices such as microcontrollers (MCU), microprocessors (MPU), field-programmable gate arrays (FPGAs), graphics processing units (GPUs) and application-specific integrated circuits (ASICs). These are vital components required for high-performance computing tasks. However, one semiconductor technology that is perhaps easily overlooked as being part of the data center chipset solution of the future, is the silicon power MOSFET. Advancements in the development of reliable, low-cost, high performance MOSFET technology will play a crucial role in the successful performance of the aforementioned state of the art processing devices that hardware systems designers and software developers are depending on to overcome the challenges facing data centers today and in the future.

IceMOS Technology applied original intellectual property to develop its own dielectric isolation technology platform over 20 years ago. This process provides high-voltage isolation between components on the same chip. There are three elements to the manufacturing process; a thick-film bonded silicon on isolator (SOI) substrates, combined with state-of-the-art high aspect ratio deep trench etching, and an oxide/polysilicon refill. This trench SOI wafer process is very commonly used in the manufacturing of Micro-Electro-Mechanical Systems (MEMS) devices. However, IceMOS was the first semiconductor company to successfully merge MEMS manufacturing techniques with sub-micron CMOS manufacturing to create the IceMOS MEMS Superjunction MOSFET (mSJMOS™) technology platform.

The mSJMOS™ combination of Silicon MOSFET technology and MEMS process technology enables a scalable high voltage Superjunction MOSFET capable of extreme performance such as low on-resistance, ultra-low gate charge, high dv/dt capability, high unclamped inductive switching (UIS) and high peak current capabilities.

Power Management from AC input to POL for Data Centers

Data centers are typically supplied with AC power from the grid, which is then distributed throughout the facility. Most of the electrical equipment used, including servers, contain microprocessors, memory, and graphics chips that all require high quality no transient DC power. This means the AC power must go through multiple stages of power conversion, resulting in power losses and wasted energy. It is both costly and inefficient.

The illustration in Figure 3 shows high voltage AC input to point of load (POL) distribution power stages for a typical data center server. The 600V mSJMOS™ Gen-1 and Gen-2 devices highlighted in the illustration covers the three power management stages of the AC to DC power conversion systems in data centers (“in-rush” current protection (ICP), power factor correction (PFC), and down converter). However, the challenges of increasing demands and greater efficiency call for a different approach than what is shown here.

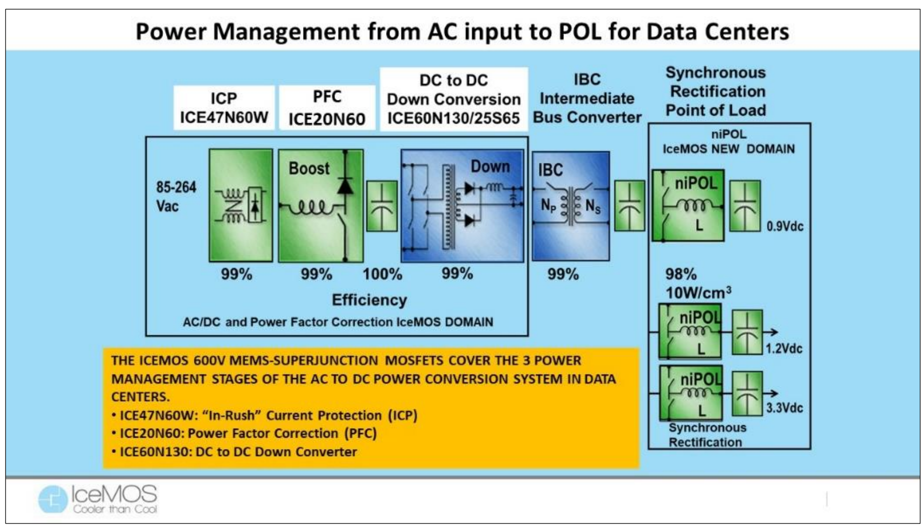

FIGURE 3: Data center power distribution stages.

A more rapid transition to higher voltage DC power distribution and conversion will directly improve efficiency. Improvements are possible even with the exponential increases in energy as voice, data, and networks converge and merge, and as the demand for data is predicted by some to double every six months worldwide.

The science behind high voltage DC power distribution is based on Ohm's law which states, *“The voltage or potential difference between two points is directly proportional to the current or electricity passing through the resistance, and directly proportional to the resistance of the circuit.”*

In the formula: **I = V/R** (where **I** = Current or Amps, **V** = Volts, and **R** = Resistance), if the voltage is doubled, the current can also be doubled with the same amount of resistance.

This means that going from 120V to 480V with 10 ohms of resistance, the current quadruples from 12Amps to 48Amps, but the power increases by a factor of 16. Higher power processors require more current, making it more difficult to deliver the current required by the processors with a 12V power train/bus. That is the primary reason for the switch to 48V to 1V at point of load (POL) requirements saving considerable energy in data center servers.

The next generation of advanced power semiconductor technology from IceMOS will establish a design platform aimed at enhancing high voltage DC distribution for data center servers.

The Next Generation of Product:
Silicon has been the most widely used starting material for electronic components since the birth of the semiconductor over 60 years ago. It offers exceptional physical properties, has a proven reliability record, is easy to manufacture, and has a relatively low cost of production. At the same time, it is no secret that Silicon has almost reached its theoretical limits, prompting researchers to focus on developing materials that are able to provide better performance in those area where Silicon falls short. Among these Silicon alternatives are various compound semiconductor materials, also known as wide band-gap (WBG) materials. Figure 4 show a side by side comparison of Silicon with two of the more popular WBG technologies, Silicon Carbide (SiC) and Gallium Nitride (GaN). Despite the fact that MEMS Superjunction technology has created a path to higher operating voltages and lower on-resistance for high-power applications, IceMOS believes that another breakthrough is needed to adequately enable peak performance of high voltage DC distribution systems.

	Silicon (Si) MOSFET	Silicon (Si) IGBT	Silicon Carbide (SiC)	Gallium Nitride (GaN)
On-Resistance	Improved by Superjunction	Conductivity Modulation	Essentially Low	Essentially Low
Practical Voltage	1 ~ 1000V	> 600V	> 600V	300 ~ 600V
Switching	Fast	Tail Current By Minority Carrier	Fast	Fast
High Temperature Operation	150°C	150°C	Potentially High	Potentially High
Reliability	Excellent	Excellent	Gate Ox Quality Concern	Current Collapse Concern
Material	Well Established	Well Established	Expensive Defect Concern	Expensive Defect Concern
Process	Si process driven by LSI and MEMS	Si process driven by LSI and MEMS	Some Processes Need Special	Some Processes Need Special
Processing Cost	Low to Moderate	Low to Moderate	High	High
Manufacturability	Good	Good	Improvement Ongoing	Improvement Ongoing

FIGURE 4: Technology performance comparison

After assessing the high-voltage market, IceMOS recognized the potential benefits for embedding a WBG semiconductors into the drain of the MOSFET. Having successfully established the mSJMOS™ technology platform by merging MEMS manufacturing techniques with sub-micron CMOS manufacturing, the next logical step for IceMOS was to take on the challenge of developing a transistor that incorporates a silicon-carbide engineered drain to take advantage of the low on-resistance performance of this WBG materials.

That idea was presented and received funding in 2021 from NASA for a Phase-I SBIR. NASA's desire was to improve the onboard high-voltage distribution bus in a spacecraft by using a more efficient power MOSFET. Using a high-voltage distribution bus allows NASA to convert energy from the source, typically a battery or a solar array, to the point of load in a more efficient way. The NASA power distribution efficiency challenge in a spacecraft is very similar to the challenge described earlier for data centers. The development work done for NASA to reduce the power consumption problem is a direct benefit to non-space applications like data centers that are facing the same challenge.

After successfully completing the Phase-I development work, NASA made the decision not to fund the Phase-II proposal. However, this important work was not done in vain. In June of 2023 IceMOS was one of only three companies to be awarded funding from the UK Space Agency to advance the development of key and strategic technologies. Development performed under this award builds on the work that was done for NASA, The focus is on delivering an Advanced Engineered Substrate that will be used to enable a high-voltage silicon carbide engineered drain MOSFET. As was the case with NASA, the goal is a more efficient high power distribution electrical systems on spacecraft for Low Earth Orbit (LEO), Middle Earth Orbit (MEO) and deep space exploration.

The WBG Power MOSFET drain structure will be tailored to be robust in harsh space radiation environments and will create a new class of vertical power transistor that can also be used for non-space applications. This next generation substrate development work will run through 2024.

The Broader Impact

The potential environmental impact of a new more efficient MOSFET technology is an exciting prospect. Uses for the IceMOS next gen device technology in commercial applications are aimed at addressing the increasing social demands for greater energy conservation. The reduction in energy loss by enabling more efficient power conversion technology can result in a significant reduction in greenhouse gases when a higher-voltage distribution system is in play.

A data center using an IceMOS device enable distributed power systems has the potential to contribute to an estimated 30-40% reduction in energy loss possible. That reduction is a saving of over 20 Tera-Watt-Hours per year. What does a saving of 20 Tera-Watt-Hour per year look like? It is the equivalent of 14,173,650 Metric Tons of Carbon Dioxide (CO_2)[1], or one of the other measurement methods as shown in Figure 5a-b.

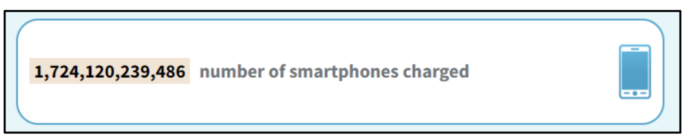

FIGURE 5a: 20 Tera-Watt-Hours equivalent in terms of CO_2 Emissions

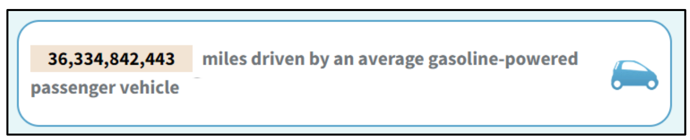

FIGURE 5b: 20 Tera-Watt-Hours equivalent in terms of Greenhouse Gas Emissions

As the focus continues to shift away from merely monitoring sustainability metrics and targets to enforcing them, this enhanced distributed power solution offers a viable path to achieving those goals.

Conclusion:

The industry consensus is that the onslaught of demand is expected to continue for faster, more flexible, and more efficient data center computing. This in turn will continue to emphasize the importance of how data center operators use and manage power at the site. The discussion around which approach or option for how to best do this is open for debate. The fact that there are multiple options to discuss is good news. It is not likely to be a single solution, but instead a combination of approaches that are needed to successfully meet this challenge.

For innovations in software-defined power or data center AI to be part of that conversation, the supporting semiconductor chipset technology must keep pace and innovate as well to support those software based strategies. While “the ask” from the software side has been is for faster MCUs and better GPUs (which consume more power), the push for advancements in Silicon Power MOSFET technology to use with those devices has been largely overlooked. WBG technologies, such as GaN and SiC are getting attention because of their performance attributes, but the limited historical reliability data and the higher manufacturing costs are concerns for many.

The IceMOS next generation Superjunction technology platform features a silicon-carbide engineered drain to take advantage of the lower on-resistance performance from WBG materials. It was originally targeted for use by NASA to address spacecraft power distribution efficiency challenges, which are in fact very similar to the challenges faced by data centers and other non-space industries using a high-voltage distributed power system. It stands to reason that the solution for addressing these challenges could also be one in the same.

References

[1] **Source:** Uptime Institute, "Global Data Center Survey 2022", UII-78 v1.0M published 14 September 2022, last updated 14 September 2022

[2] **Source:** US Environmental Protection Agency (EPA) - Greenhouse Gas Equivalencies Calculator https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator