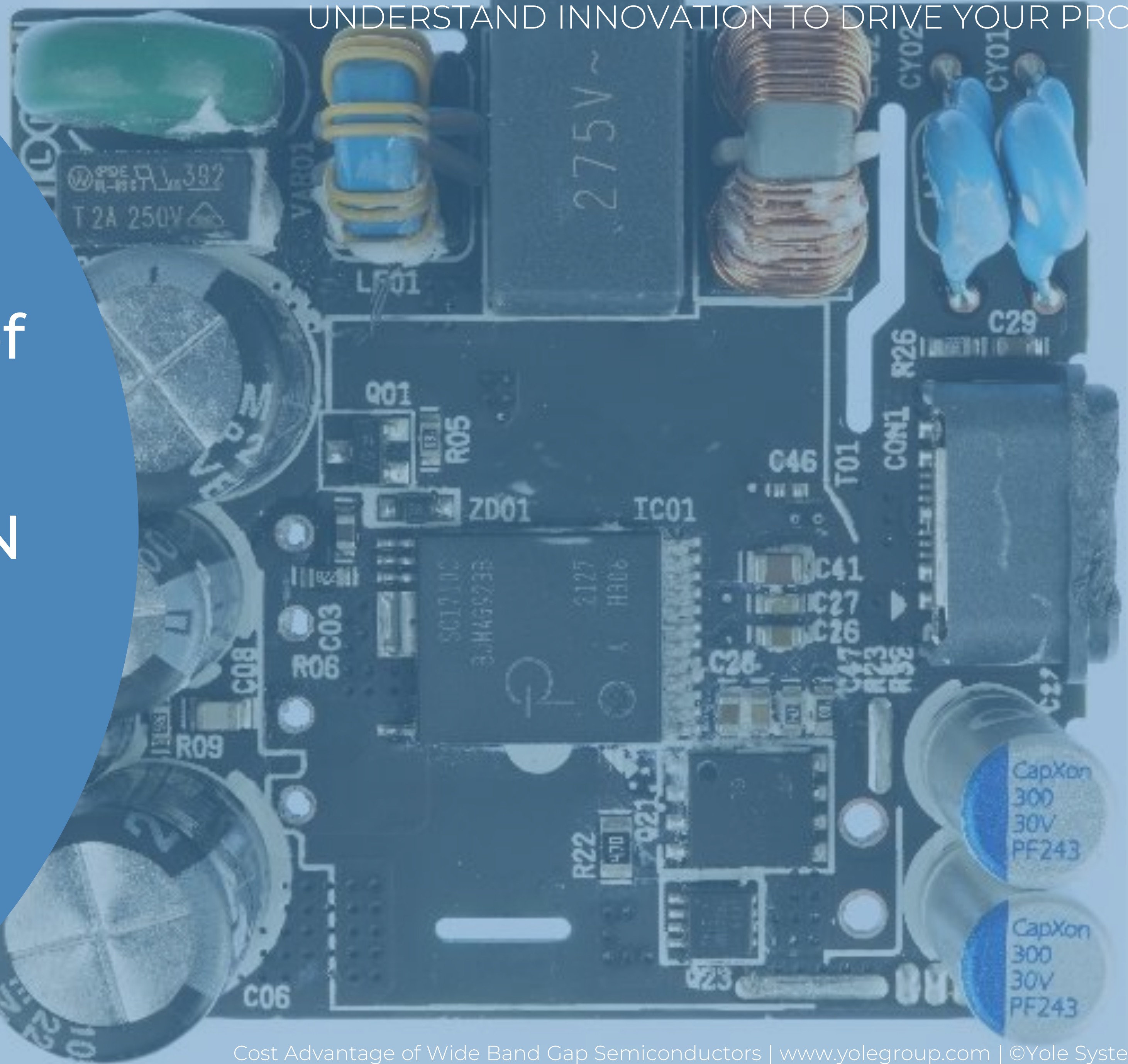
Cost Advantage of Wide Band Gap Semiconductors with focus on GaN



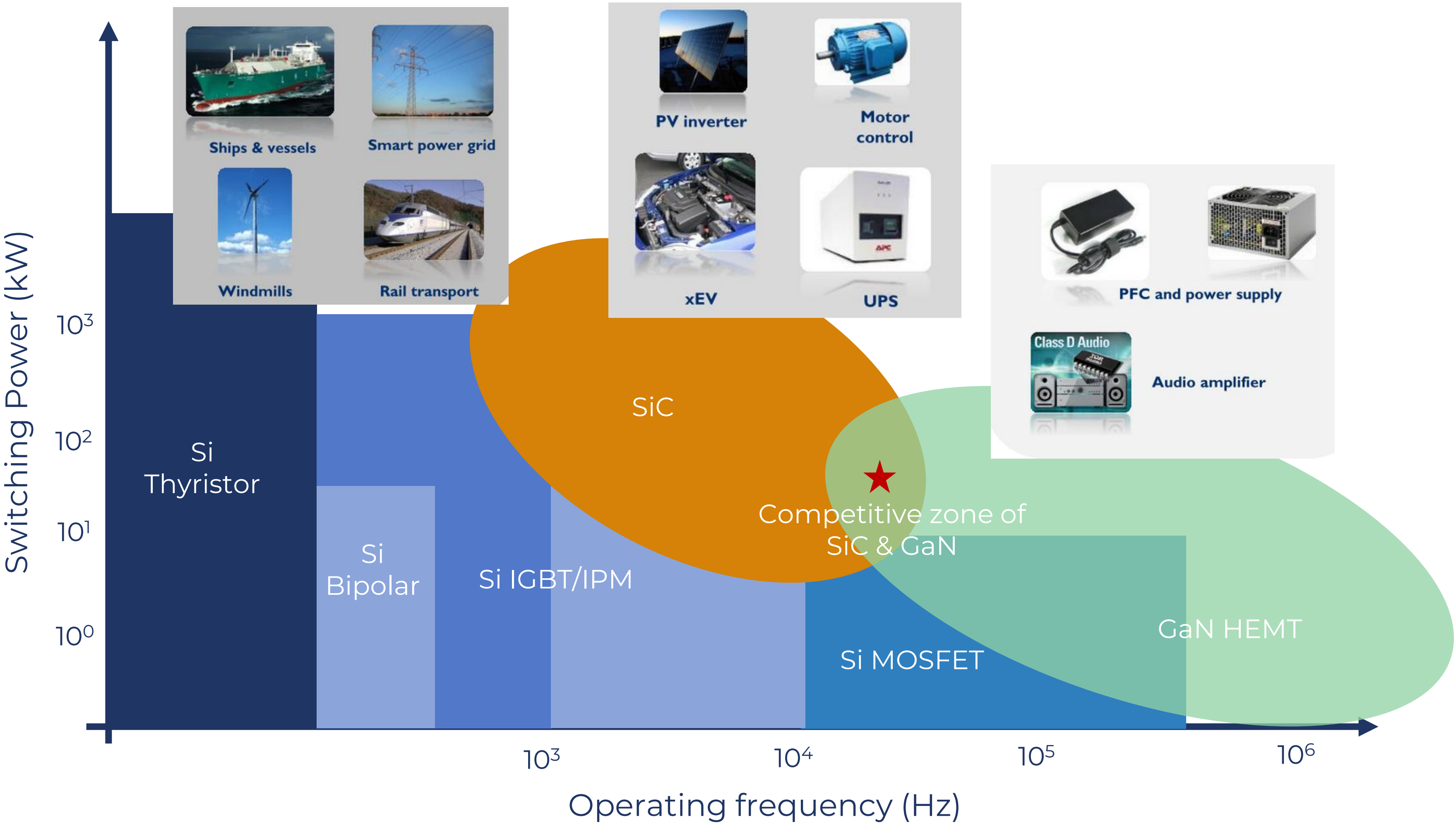
YOLE SystemPlus

CONTENT

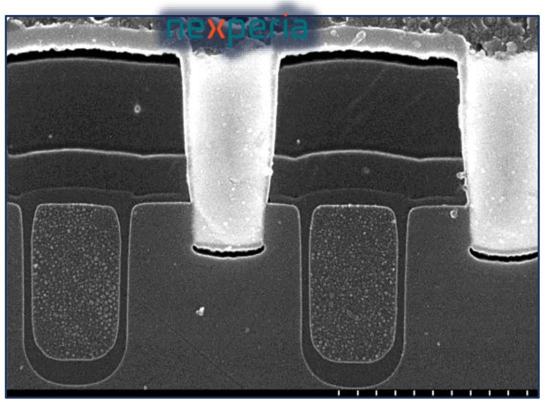
- Power Conversion Solutions
- Si Power Semiconductor Designs and Limitations
- Technical Comparison - Si vs SiC vs GaN
- GaN Device Solutions
- Cost Considerations for Discrete Power Device
    - Wafer Cost Considerations
    - System Level Cost Considerations
- Recommendations for further cost savings

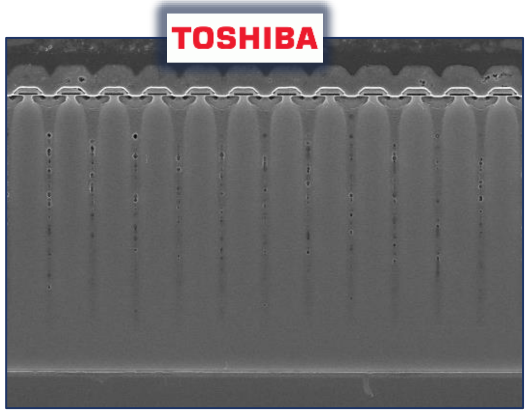
POWER CONVERSION SOLUTIONS

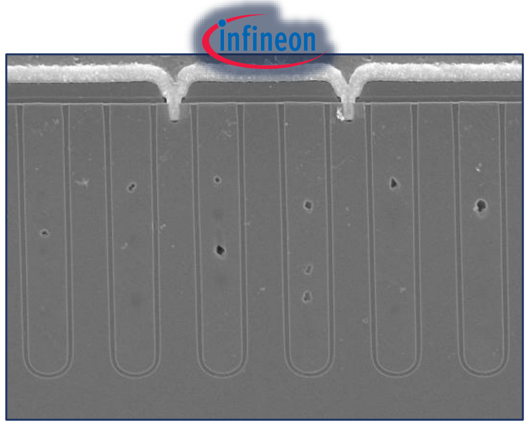
- Power electronics applications is still dominated by Si technologies, but we are seeing SiC and GaN competing for applications mainly in the medium and high voltage applications.



POWER TRANSISTOR DESIGNS AND LIMITATIONS

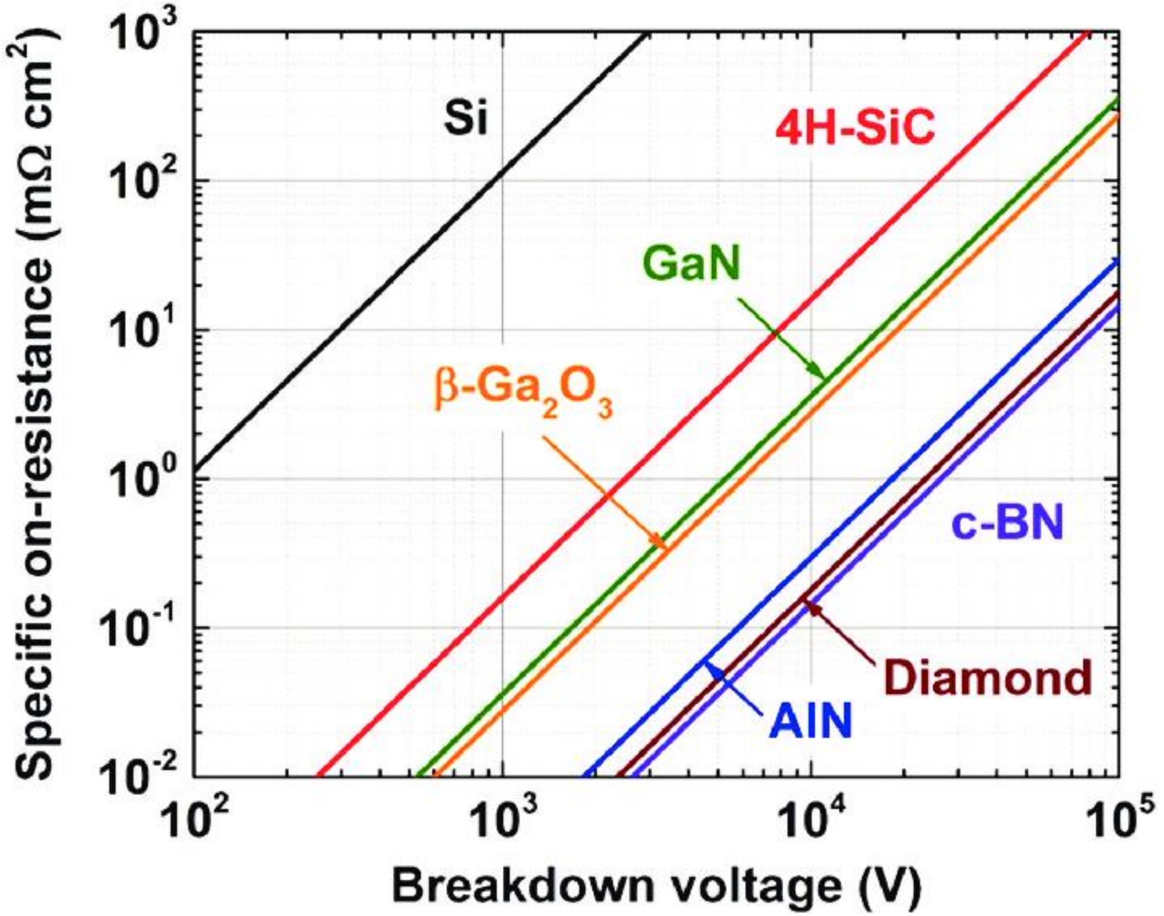






	Si Power MOSFET	Superjunction MOSFET	IGBT
Voltage Range	12 V - 600 V	600 V to 1000 V	400 V up to 3kV
Device type	Unipolar	Unipolar	Bipolar
On resistance	High	Low	Lowest
Cost	✓	✓✓✓	✓✓
Main Applications	Class D Audio amplifier, PFC power supply, consumer appliances	Hybrid/Electric Vehicle, Industrial Controller, PV Inverters, UPS, Hybrid/Electric Vehicle	Industrial Controller, PV Inverter, HV traction, Wind Turbines
Main Players	VISHAY, TOSHIBA, nexperia, ST life.augmented, RENESAS, infineon, Littelfuse, Fuji Electric, MITSUBISHI ELECTRIC, ROHM, onsemi	ST life.augmented, RENESAS, infineon, VISHAY, MITSUBISHI ELECTRIC, ROHM, TOSHIBA	ST life.augmented, RENESAS, infineon, Littelfuse, Fuji Electric, MITSUBISHI ELECTRIC, ROHM, onsemi, TOSHIBA

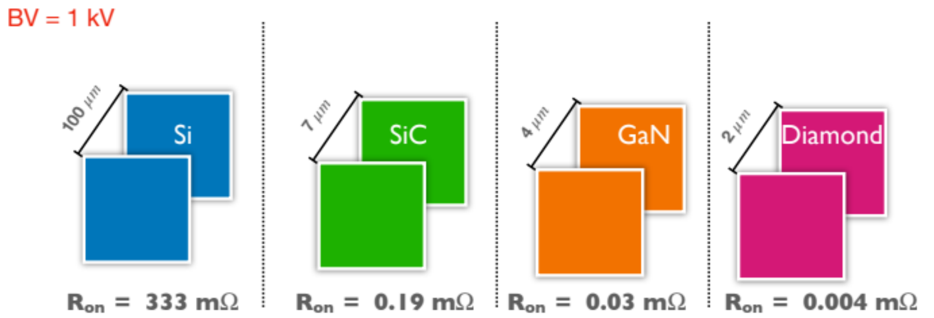
TECHNICAL COMPARISON - SI VS SIC VS GAN



Source: J.Y Tsao, Ultrawide-Bandgap Semiconductors: Research and Opportunities

Theoretical limits define by materials properties

Property	Symbol	Si	4H-SiC	GaN	$\beta - Ga_2O_3$	Diamond
Bandgap	Eg(eV)	1.1	3.23	3.45	4.5	5.45
Sat. Drift Velocity	$v_s[10^7 cm/s]$	1.0	2.0	2.2	-	1.1
Electron mobility	$\mu_n[cm^2/V.s]$	1500	1000	1250	300	1000
Hole mobility	$\mu_p[cm^2/V.s]$	480	100	200	-	2000
Breakdown field	E_m [MV/cm]	0.3	3	2	8	10
Dielectric constant	ϵ_r	11.8	9.8	9	10	5.5
Thermal Conductivity	λ	1.5	5	1.5	0.11	22
BFM(absolute)	(MW/cm^2)	42	20000	8000	140000	970000
BFM(relative)	[Si=1]	1	550	190	3200	23000



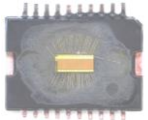
Manufacturing challenges vs Cost vs Reliability vs integration

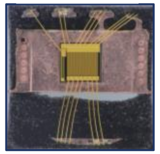
GAN DEVICE INTEGRATION

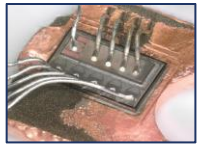
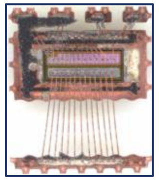
CS INTERNATIONAL CONFERENCE

Single switch

Innoscience 英诺赛科 · Infineon · GaN Systems · Panasonic · CGD Cambridge GaN Devices · ST life.augmented · nexperia · transphorm · GANPOWER International · EPC Efficient Power Conversion



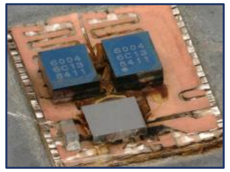
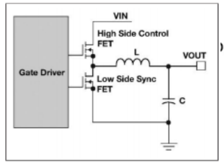


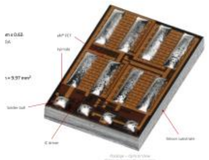
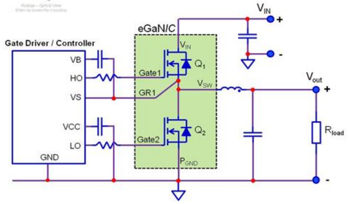




Single switch' includes only one GaN device in the package. It is the simples solution on component level, but it implies more effort at the system level. Moreover, more discrete devices needed in a system.

Multiple switches

Texas Instruments · EPC Efficient Power Conversion · GANPOWER International

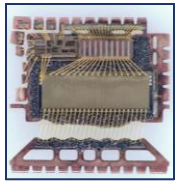
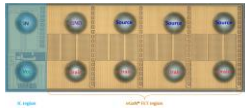



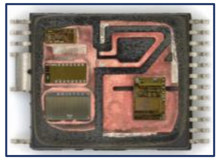
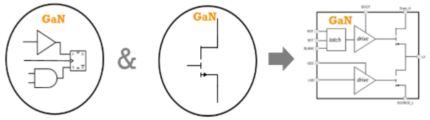



More than one GaN HEMT is integrated in a chip, for example two HEMTs for a half-bridge configuration. It provides a more compact design and higher efficiency to the system.

Multiple functions

Texas Instruments · EPC Efficient Power Conversion · Navitas · power integrations · ST life.augmented · Tagore Technology · EXAGAN Accelerate Power Transition · wise-integration · VisIC Technologies · Innoscience 英诺赛科

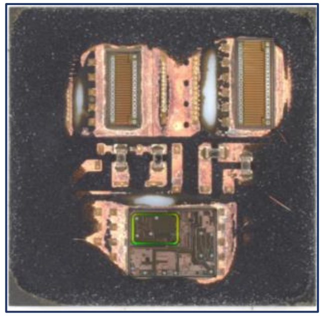



Integration of a GaN HEMT and the driver in one chip for high efficiency and good high-frequency operation. Some manufacturers using D-mode GaN integrate the driver as well.

Multiple switches and functions

Navitas · GANPOWER International · Wise integration · EPC Efficient Power Conversion · Texas Instruments · ST life.augmented



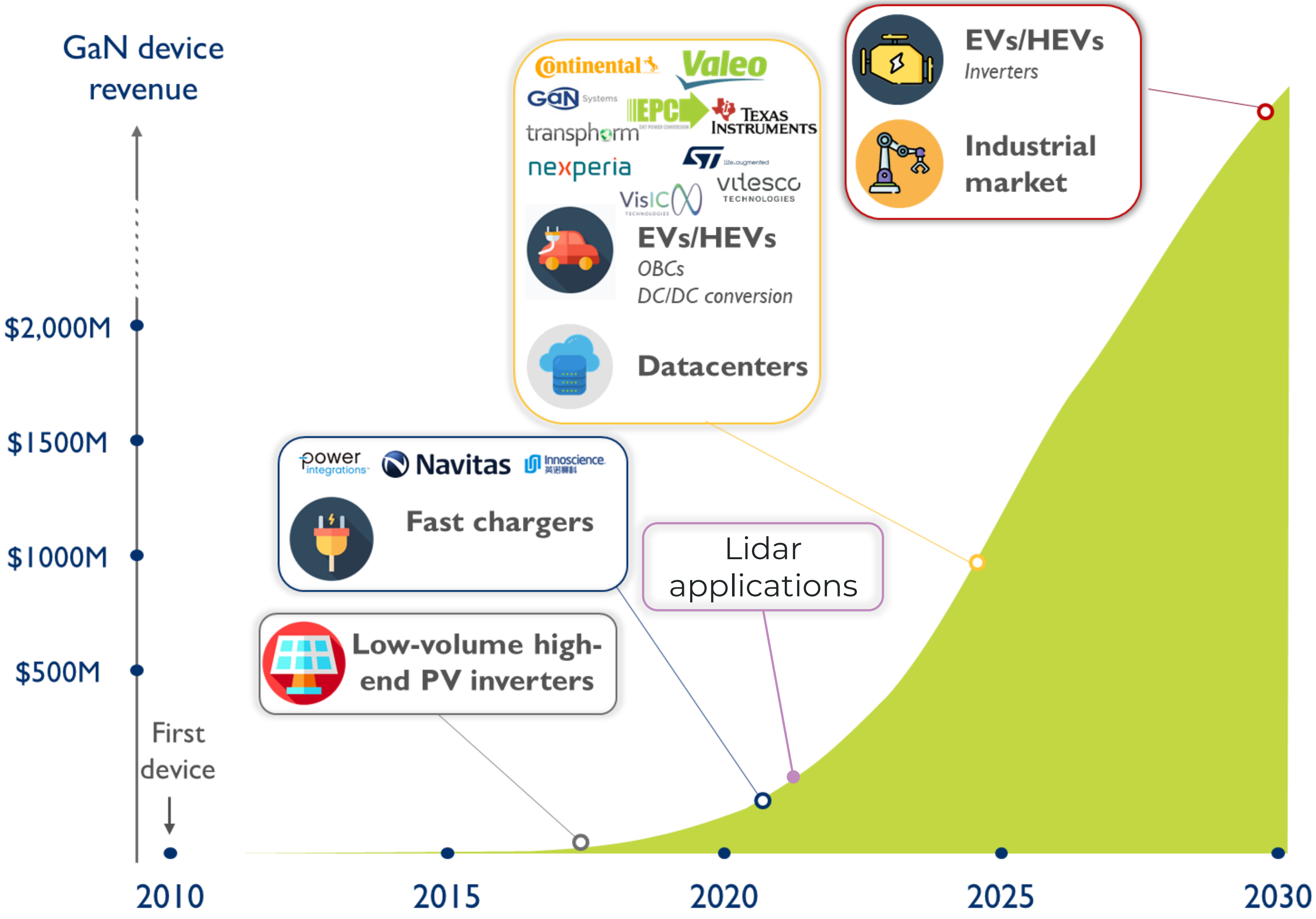
Currently the implementation of multiple switches and functions is done by integrating multiple chips in a single package.
To monolithically integrate switches there is a need for strict control of isolation to avoid any current flow or latch-ups.

*** Non-exhaustive list of companies*

GAN POWER DEVICES MARKET

Long term evolution

- Consumer fast-charger applications will continue to drive the GaN market in the short term.
- Volume shipments will ramp up in datacenters and EVs/HEVs in the mid- to long term.



Source: GaN Power 2022, Yole Intelligence

FAST CHARGERS: GaN VS. Silicon

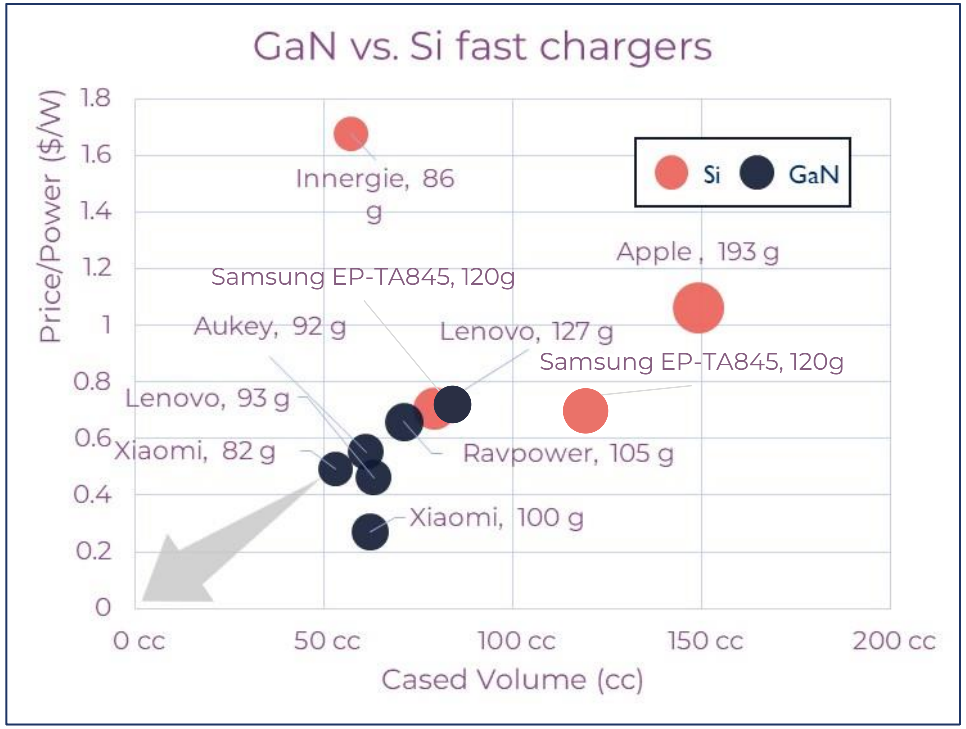
Faster, more power, smaller, lighter and lower cost

The trend is towards smartphones with a bigger screen and larger battery capacity. Fast charging is becoming a must-have technology. GaN offers numerous benefits over silicon MOSFETs such as a small form factor, high efficiency and high performance.

According to industry feedback, GaN enables an interesting cost/performance ratio compared to silicon MOSFETs beyond 45W.

On the other hand, advances in silicon MOSFETs' performance are still ongoing, with enhanced topologies like active clamp fly-back (ACF). In fact, Xiaomi have silicon MOSFET fast-chargers that can reach 120W.

Another important criteria is thermal management. In the system as a whole, the GaN solution is likely to have lower losses.



Samsung's 45W fast charger based on silicon
52x53x30 mm
Power density: 0.55 W/cm3

EP-TA845

Samsung's 45W fast charger based on GaN
48x44x28 mm
Power density: 0.76W/cm3

EP-T4510

Xiaomi's 120W fast charger based on silicon
64x61x28 mm
Power density: 1.1 W/cm3

MDY-12-ED

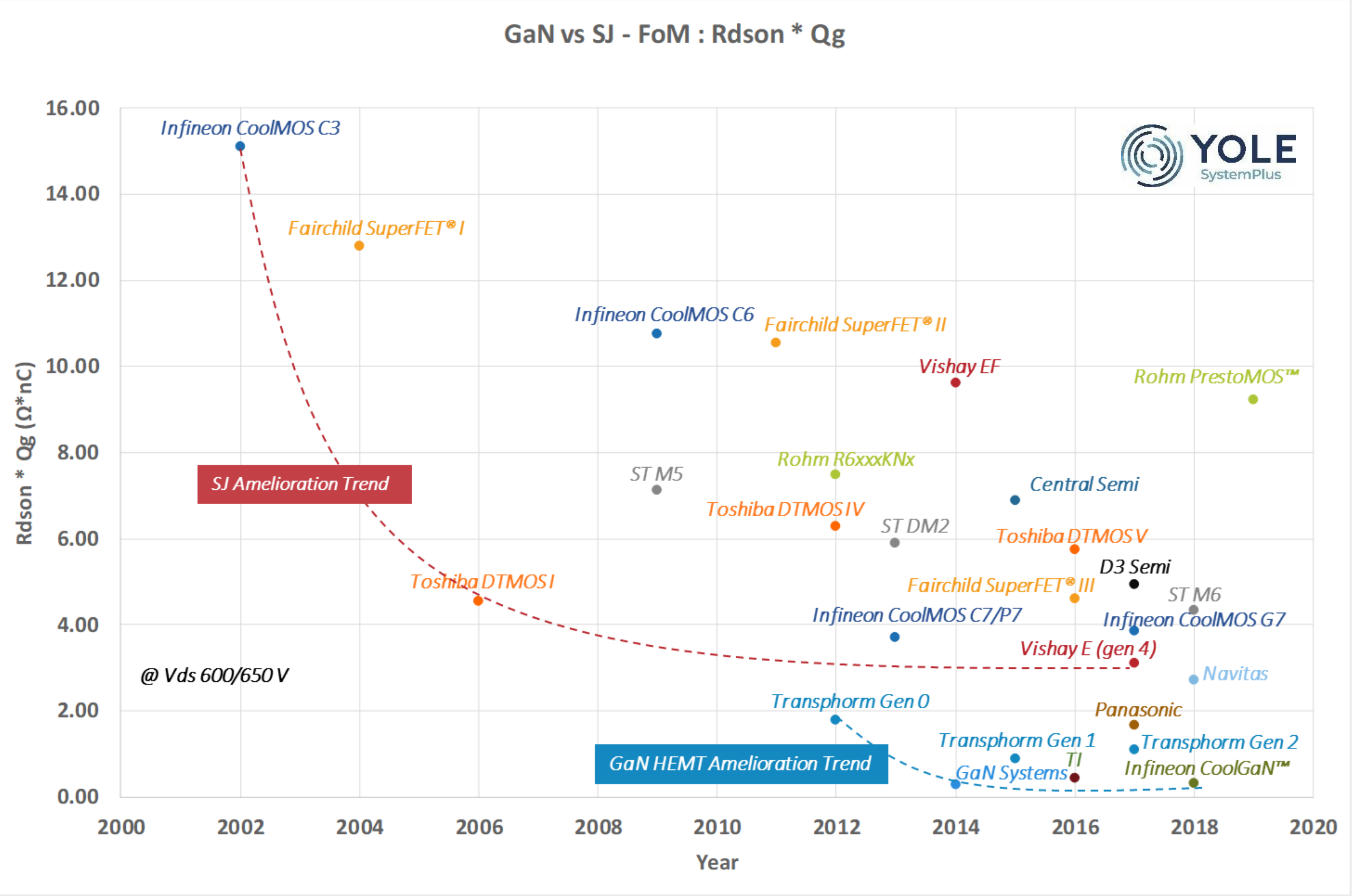
Xiaomi's 120W fast charger based on GaN
56x56x28 mm
Power density: 1.37 W/cm3

MDY-13-ET

- The bubble size represents the weight in grams of the cased charger. **All devices have output powers between 55-65W.**

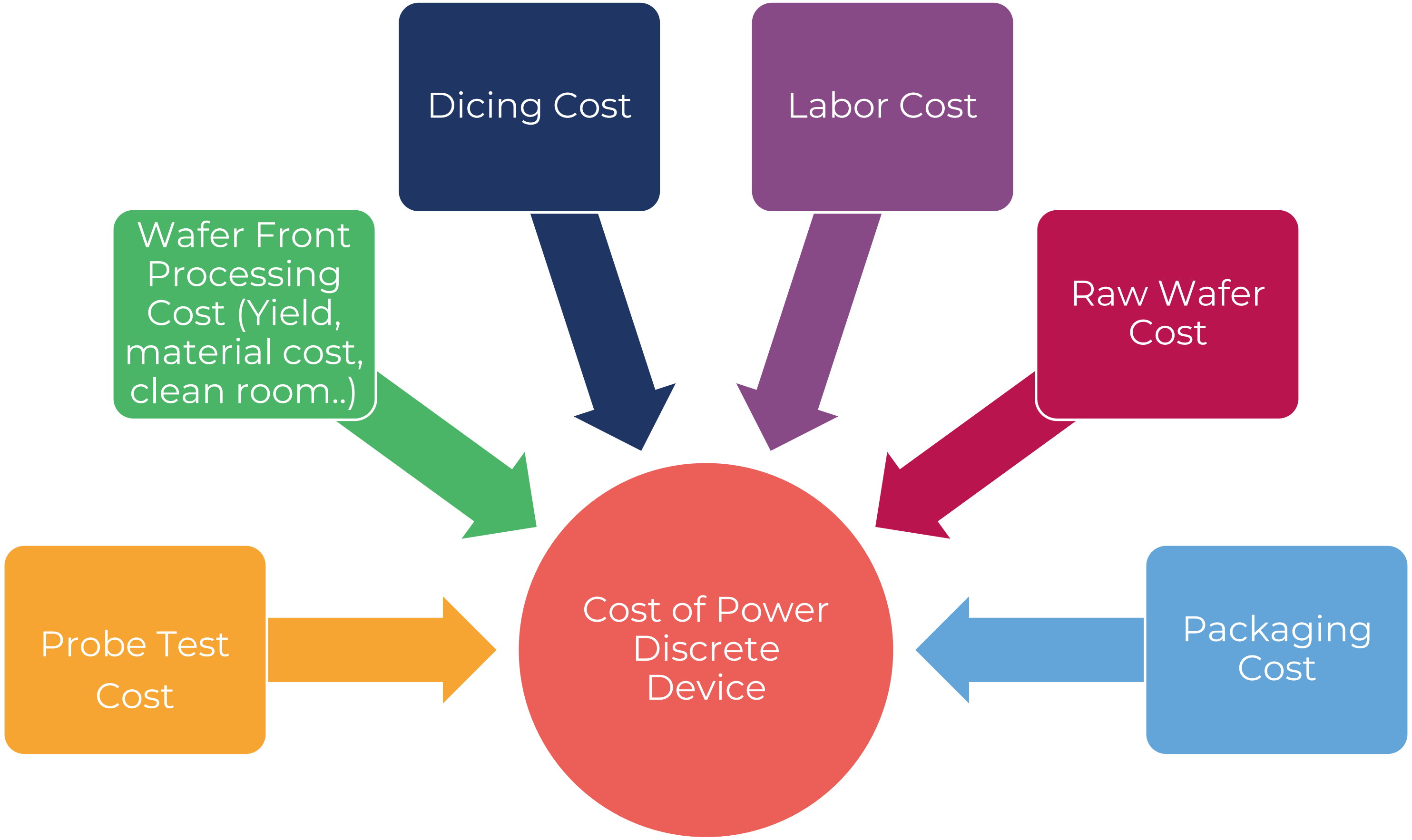
TECHNICAL COMPARISON GAN VS SI SUPERJUCTION

- Though relatively new technology, the FoM of GaN devices (650 V) are already competing with silicon superjunction devices and surpassing their performances.
- We expect to see a strong competition and continue replacement of SJ applications with GaN devices in the 600/650 V application range.



COST CONSIDERATIONS FOR DISCRETE POWER DEVICE

- ✓ Single chip vs Multi-chip solutions
- ✓ Die size (small vs large)
- ✓ Labor Cost – Supply chain
- ✓ Raw wafer (150 mm vs 200 mm vs 300 mm)
- ✓ Material Cost/Consumable Costs
- ✓ Package Assembly Cost

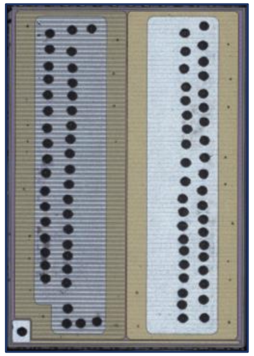


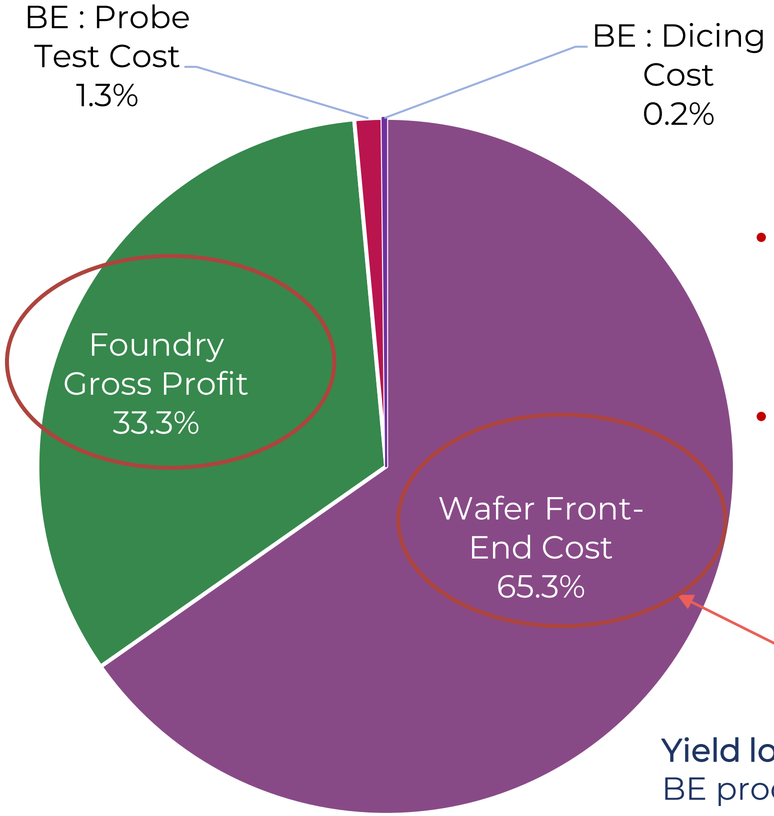
At Yole SystemPlus, we have tools to model and estimates all related manufacturing cost to near market price.

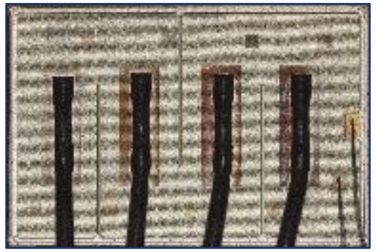
COST COMPARISON GAN VS SI SUPERJUNCTION – WAFER LEVEL

650 V Si Superjunction vs GaN

Total Wafer Cost Breakdown for GaN 650 V HEMT devices



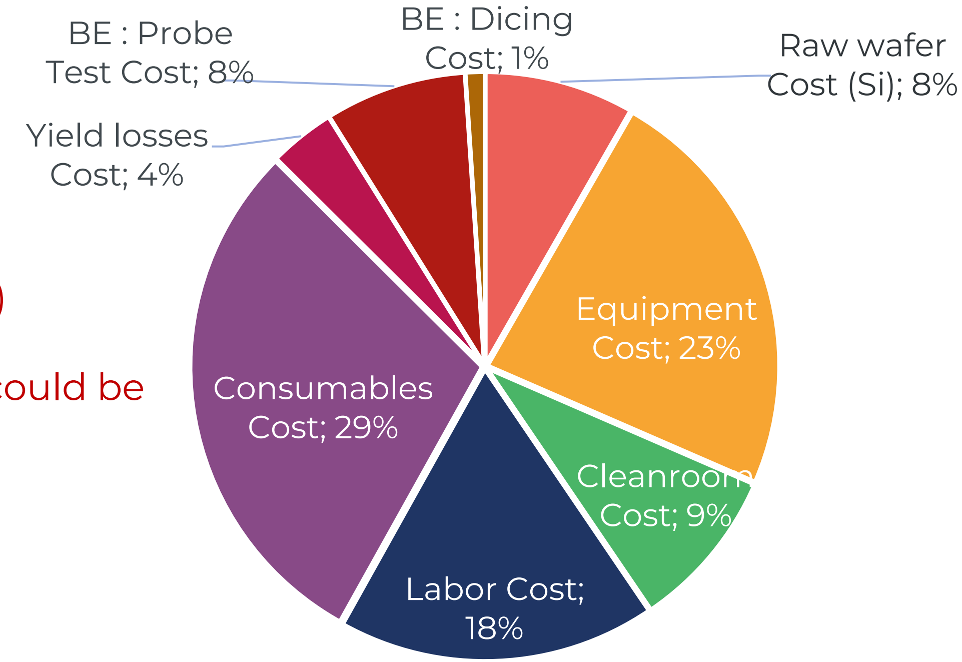




- Manufacturing Yield Improvements. (Si > 95%, GaN < 85 %)
- Vertical Integration could be considered.

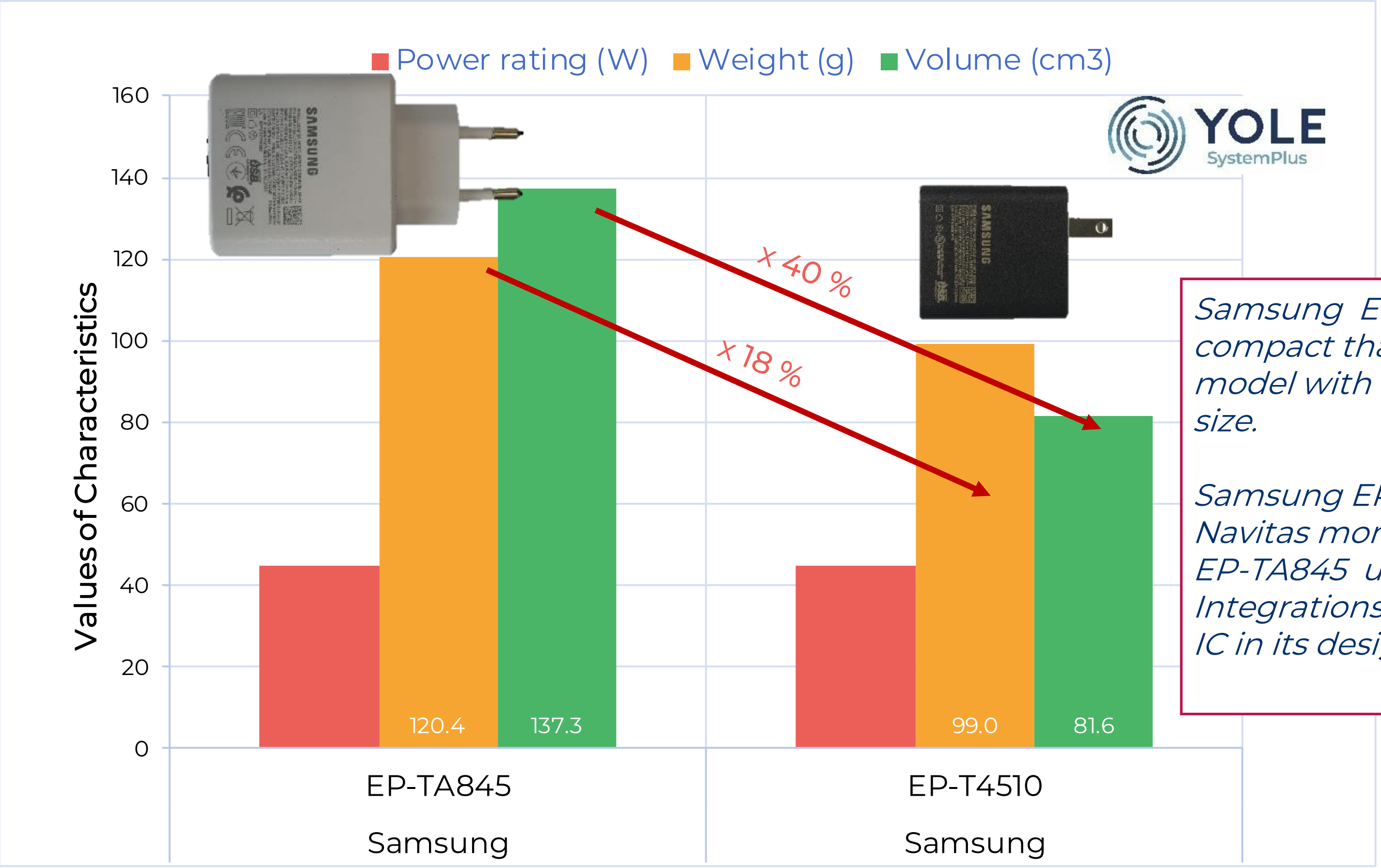
Yield loss Cost, Epitaxy Cost, FE & BE process, Raw Wafer

Average Total Wafer Cost Breakdown for 650V Superjunction MOSFET



SAMSUNG POWER ADAPTERS – BOM COMPARISON

Samsung 45W Power Adapters (GaN vs Si solution)

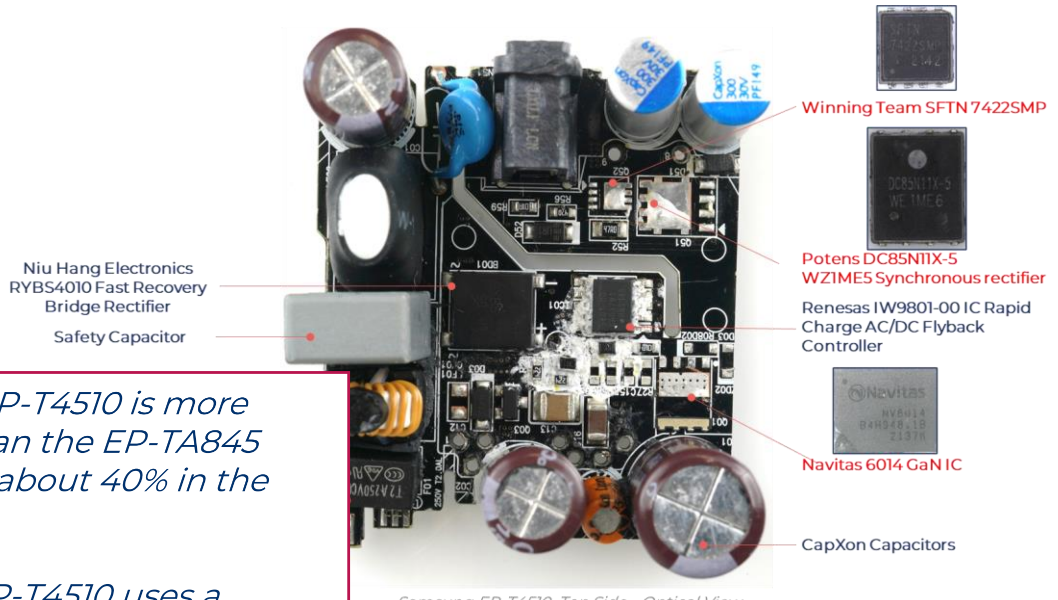


Si based Charger

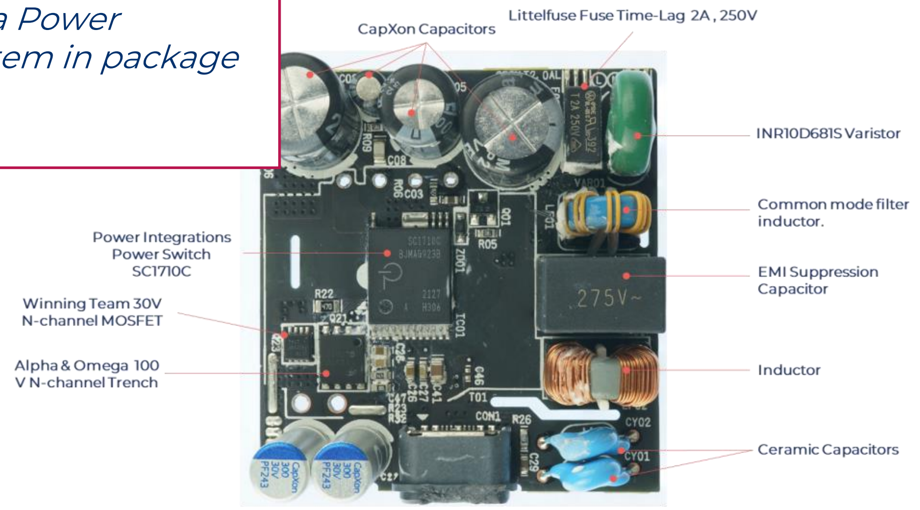
GaN based Charger

Samsung EP-T4510 is more compact than the EP-TA845 model with about 40% in the size.

Samsung EP-T4510 uses a Navitas monolithic IC while the EP-TA845 uses a Power Integrations system in package IC in its design.



Samsung EP-T4510 Top Side - Optical View
©Yole SystemPlus 2023



Samsung EP-TA845 Top Side - Optical View
©Yole SystemPlus 2023

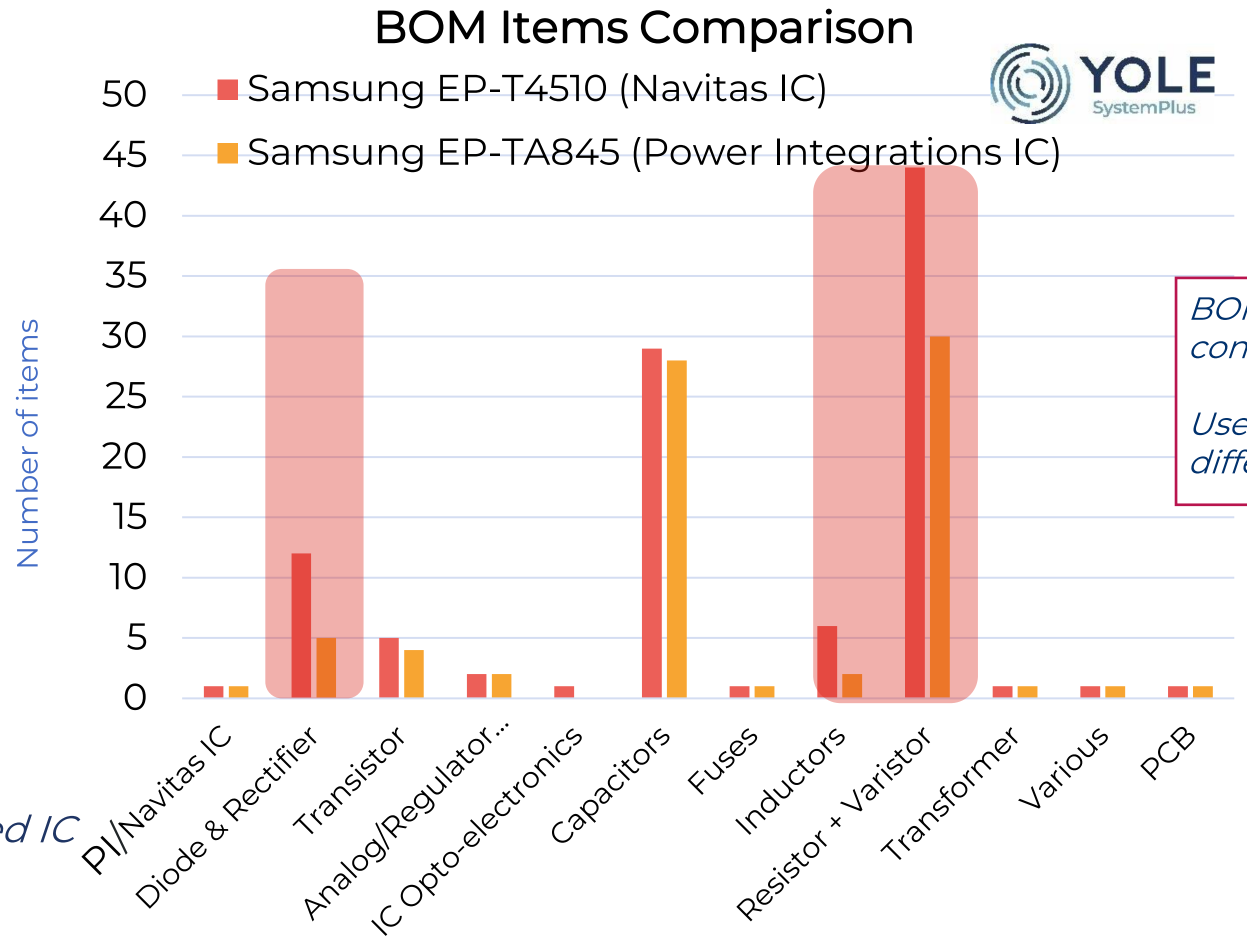
COST COMPARISON GAN VS SI CHARGER – SYSTEM LEVEL

Samsung 45W charger EP-T4510 vs EP-TA845 model

- For 45W, the Samsung charger EP-T4510 model uses more resistors, inductors and rectifiers elements than the EP-TA845 model.

Navitas GaN IC

Power Integrations Si based IC



BOM Items is a design choice consideration.

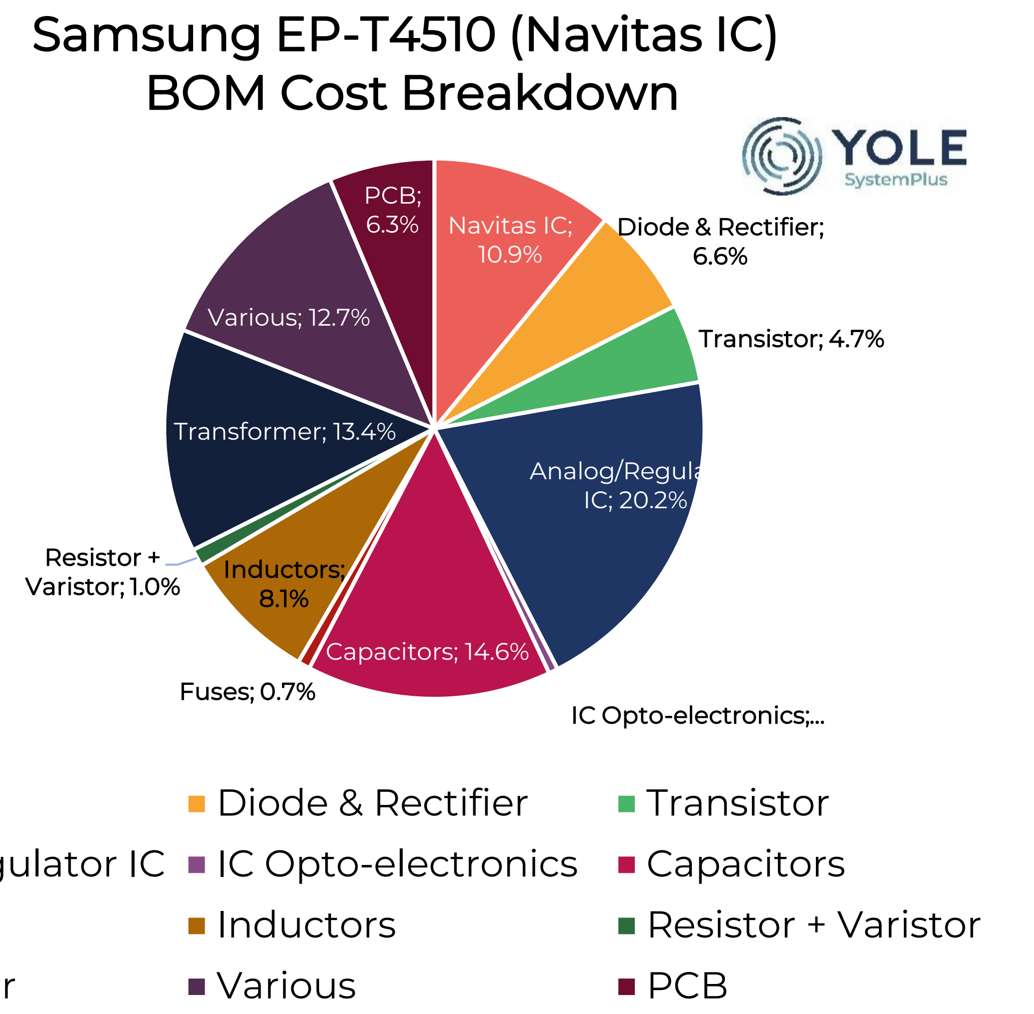
Use of GaN to replace Si requires a different design considerations.

COST COMPARISON GAN VS SI CHARGER – SYSTEM LEVEL

Samsung 45W charger EP-T4510 (using Navitas NV6014 GaNFast IC)

Component Category		Items	% of total Chip Set Cost
Power	Navitas IC	1	10.9%
Power	Diode & Rectifier	12	6.6%
Power	Transistor	5	4.7%
IC	Analog/Regulator IC	2	20.2%
IC	IC Opto-electronics	1	0.6%
Passive	Capacitors	29	14.6%
Passive	Fuses	1	0.7%
Passive	Inductors	6	8.1%
Passive	Resistor + Varistor	44	1.0%
Passive	Transformer	1	13.4%
Mechanics	Various	1	12.7%
Mechanics	PCB	1	6.3%
	Total	104	100.0%

- The regulator IC components represents 20% of the BOM Cost.
- Navitas GaN IC cost contribution is just 10.9% of the total BOM Cost



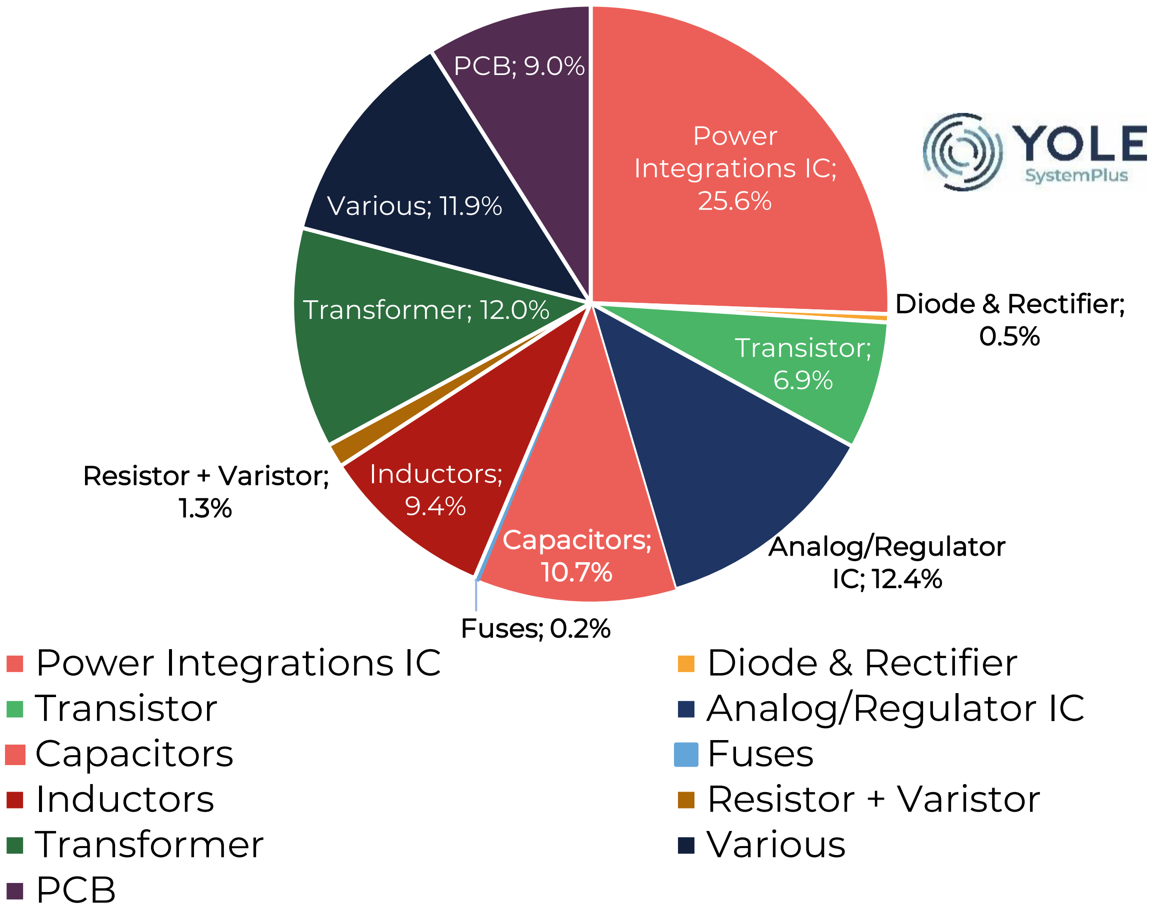
BOM COST COMPARISON

Samsung 45W charger EP-TA845 (Power Integrations SC1710 IC)

Component Category		Items	% of total Chip Set Cost
Power	Power Integrations IC	1	25.6%
Power	Diode & Rectifier	5	0.5%
Power	Transistor	4	6.9%
IC	Analog/Regulator IC	2	12.4%
IC	IC Opto-electronics	0	0.0%
Passive	Capacitors	28	10.7%
Passive	Fuses	1	0.2%
Passive	Inductors	2	9.4%
Passive	Resistor + Varistor	30	1.3%
Passive	Transformer	1	12.0%
Mechanics	Various	1	11.9%
Mechanics	PCB	1	9.0%
	Total	76	100.0%

- Power Integrations SC1710 IC represents 25.6% of the BOM Cost.

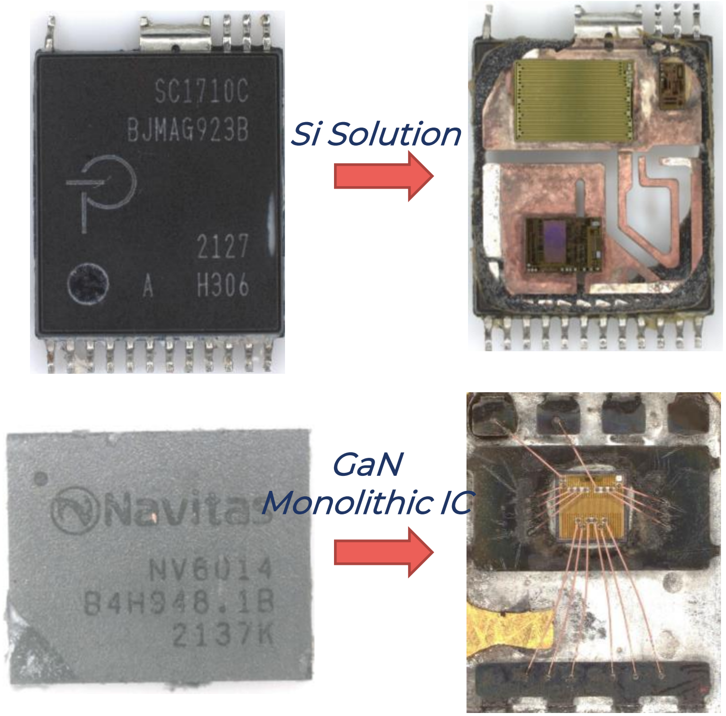
Samsung EP-TA845 (Power Integrations IC) BOM Cost Breakdown

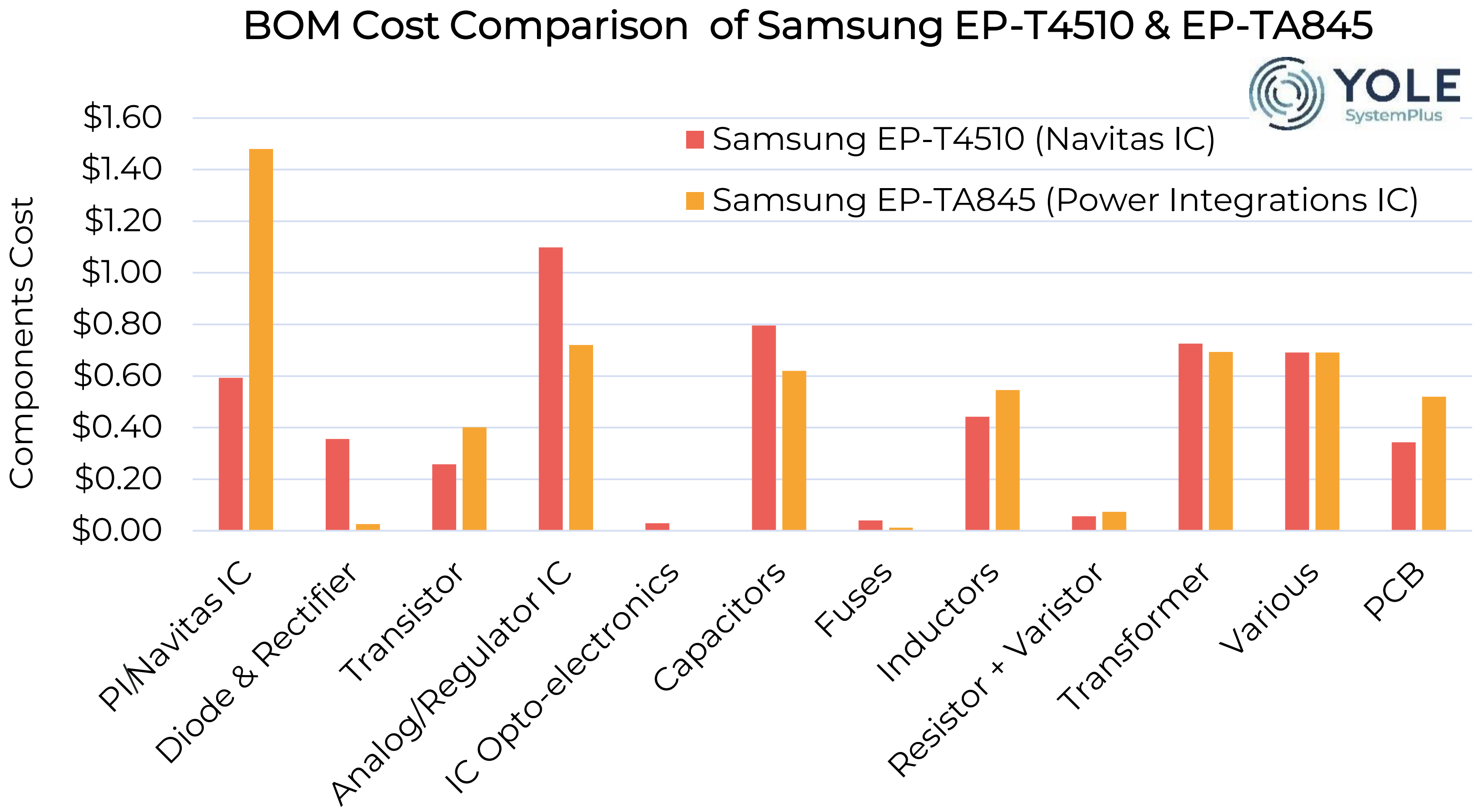


BOM COST COMPARISON

Samsung 45W charger EP-T4510 vs EP-TA845 model

- Although Samsung EP-TA845 model uses less components, its total BOM cost is still higher than that of the EP-T4510 model.
- The Power Integrations IC Si based IC in EP-TA845 model cost more than the Navitas GaN IC used in the EP-T4510 model.





Is GaN winning the cost challenge?

RECOMMENDATIONS AND CONCLUSION

For further cost savings on GaN adoptions in power devices, the following propositions are made:

- Yield improvements on wafer level.
- Transition to larger wafer size (200 mm)
- Design awareness for cost savings.
- Review of current business model towards vertical integration.
- More market adoption (in automotive, data centers) could reduce price of device in the markets.

Thank you for your attention