New Opportunities for Gallium Nitride in Power, Sensing and RF

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Home of enabling technologies

Some Opening Comments

- There used to be a saying ‘GaN is the material of the future – and always will be.’
- It wasn’t long ago and implied that we would never get to where we are today.
- But for GaN Power
  - Market forecasts for >$2 Billion industry by 2028.
  - Huge capacity expansions and M&A across the whole supply chain.
  - Forecast for >928K GaN epi wafers per year (6” equivalent) by 2028.

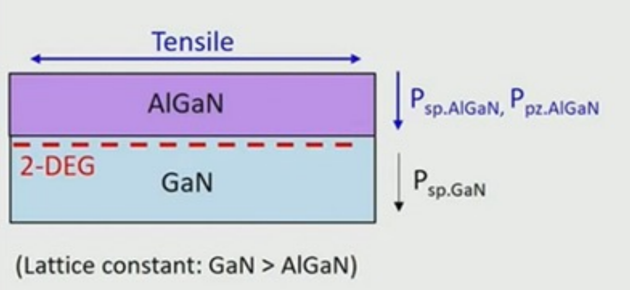
- It helped that Zero Carbon initiatives pushed the need for high efficiency PE.
- There is now growing confidence in the maturing GaN supply chain.
- This opens new opportunities for GaN in existing Si and GaAs applications as well as new areas where Si can’t compete.

Presentation Outline

- What makes GaN special? – Key Properties
- Comparative Figures of Merit for Power and RF.
- Epitaxial GaN HEMTs – Challenges and Substrate Choice.
- Market Challenges and New Opportunities.
- Gan for Wireless, Harsh Environment Sensing.
- Conclusion – Where will GaN win new market share?

So What Makes GaN Special?

- **It's the combination of wide band gap and 2 dimensional electron gas (2DEG) that makes GaN perfect for high power and high speed switching.**
- Combination of spontaneous and piezo-electric polarisation results in a discontinuity at the AlGaN/GaN interface, leading to a 2DEG.
- High sheet carrier density – can be tailored by increasing Al composition and thickness of AlGaN barrier.
- For 25% Al and 20nm typical Ns = 7.7E12 cm-2.
- Charge carriers without doping – no scattering losses!
- Results in high electron mobility



Power Semiconductor Materials

Properties	Si	SiC(4H)	GaN
Crystal Structure	Diamond	Hexagonal	Hexagonal
Energy Gap (eV)	1.12	3.26	3.4
Breakdown Field (Ecrit) (V.cm x 10^6)	0.3	2.8	3
Electron Mobility (cm²/V.s)	1400	900	1250
Electron Mobility (device)	1000	<100	1500 - 3000
Thermal Conductivity (W/cm°C)	1.5	4.9	1.3
Baliga FOM = $\varepsilon_0 \varepsilon_r \times \mu \times Ecrit^3$	1	675	3000

RF Semiconductor Materials

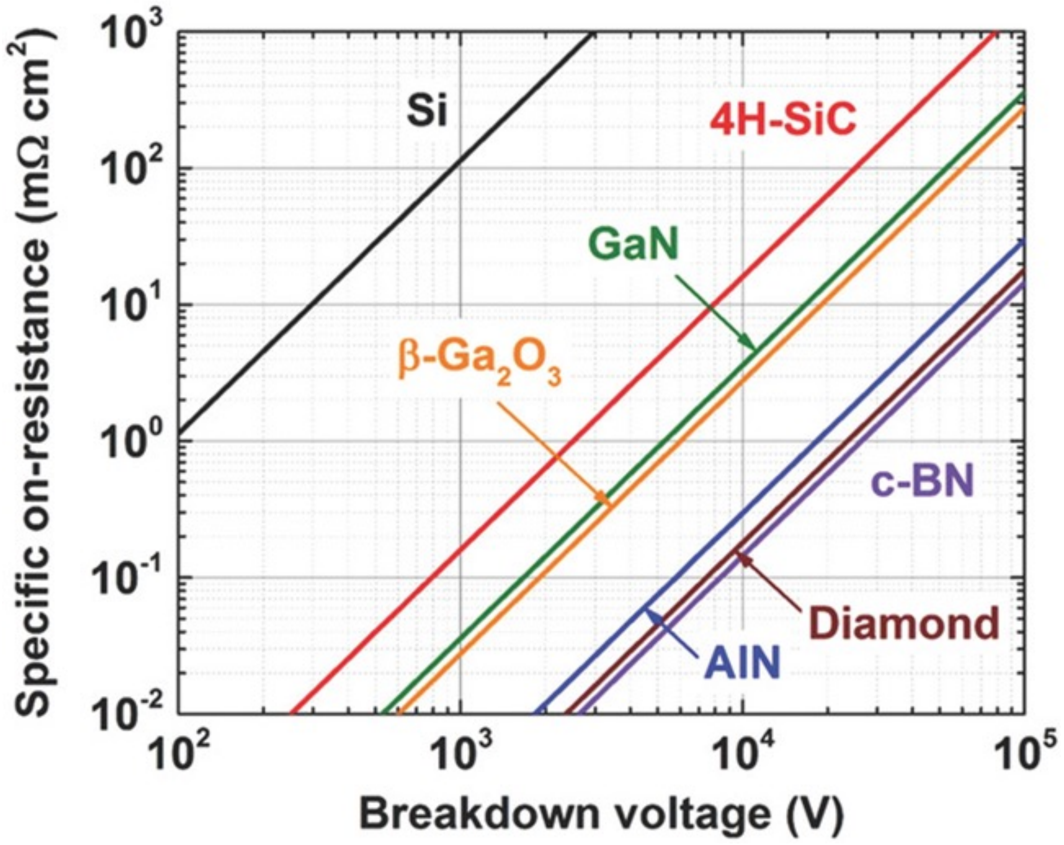
Property	Si	GaAs	GaN
Bandgap (eV)	1.1	1.42	3.4
Saturation Velocity cm/s x 10^7	1.0	1.2	1.0
Critical Field Ecrit (MV/cm)	0.3	0.4	3.0
Johnson FOM (normalised to Si)	1	2.7	27.5
Thermal Conductivity (W/cm-K)	1.5	0.46	1.7

Advantages of GaN and other WBG materials over Silicon

Unipolar Limit

$$R_{DS,on} \cdot A = \frac{4\,V_B^2}{\underbrace{\varepsilon_0 \varepsilon_r \mu E_{crit}^3}_{\text{Baliga FOM}}}$$

- **E**$_{crit}$ is the dominant materials parameter for $R_{DS,on}$ .A for a given breakdown voltage.
- Higher breakdown fields means high voltage can be supported with much thinner material.
- Huge improvement in $R_{DS,on}$ (on-resistance).
- Reduction in resistive losses. (Heat).



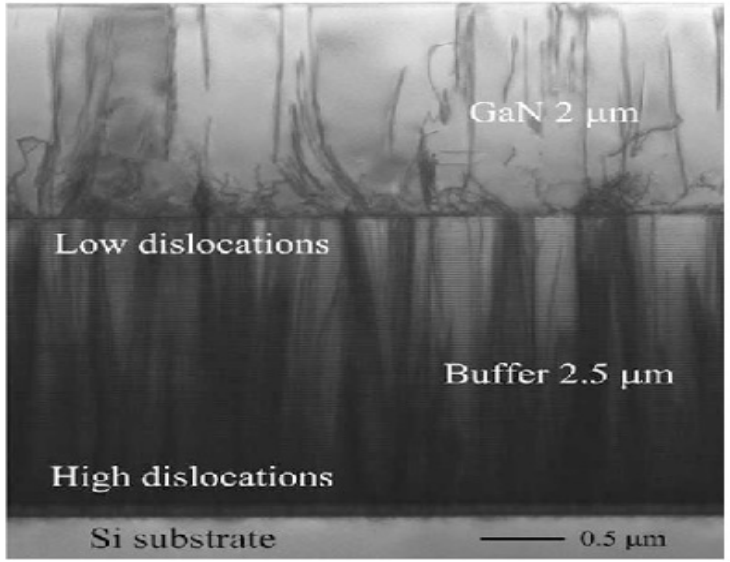
If GaN is better than SiC – Why isn't it bigger than SiC ?

- **Most of the challenges relating to GaN devices are attributable to the challenges of hetero-epitaxy.**
- **Large diameter bulk GaN wafers are not currently available (Though they could be soon).**
- **Bulk SiC wafers have been available since 1991 (Cree) enabling >30 years of device development.**
- **Defects related to lattice mismatch and differences in coefficients of thermal expansion degrades performance and reliability.**
- **We have engineered ways to mitigate this but it ultimately limits device performance.**
- **Bulk GaN promises to be a total game changer – especially for vertical power devices ≥ 1200V.**

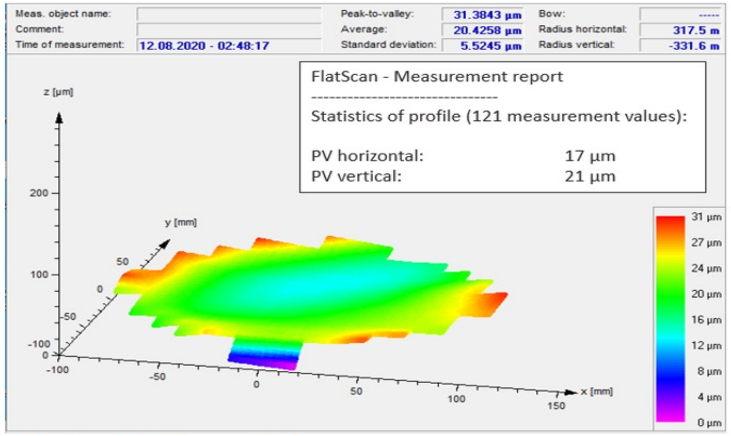
Parameter	Si	Sapphire	SiC	GaN
Lattice mismatch	−17%	−33%	3.5%	0
Thermal Mismatch	116%	−23%	24%	0
TDD (/cm^2)	~10^9	~10^9	~10^7	~10^4

QST
-17%
0
~10^8

Defect Control

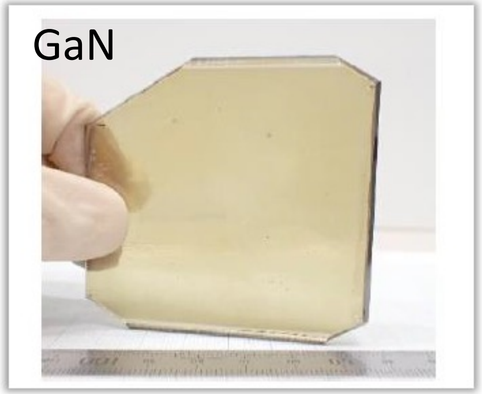


Bow Control

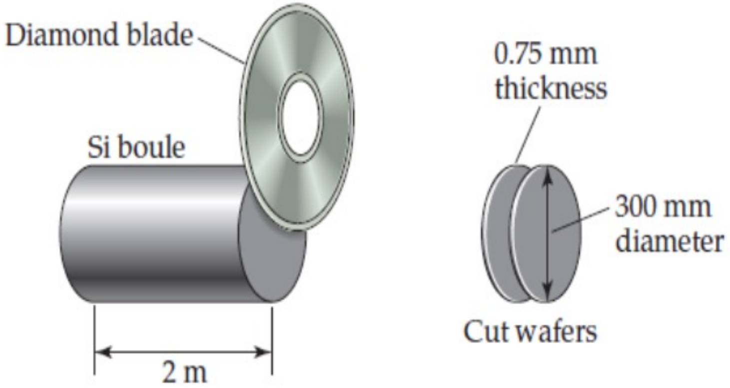


*Peak to Valley equivalent to warp

WBG Substrate Availability/ Maturity Versus Silicon



SCAAT™-LP 2-inch+ crystal



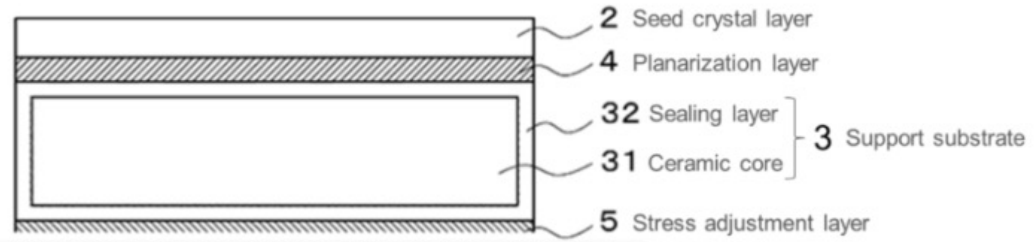
- Silicon is a mature technology – wafers are easy to manufacture at low cost.
- SiC much more challenging but now mainstream.
- 150mm bulk GaN wafers forecast by 2025 from Mitsubishi. (2023 estimate)

SCAAT™-LP 4-inch+ crystal

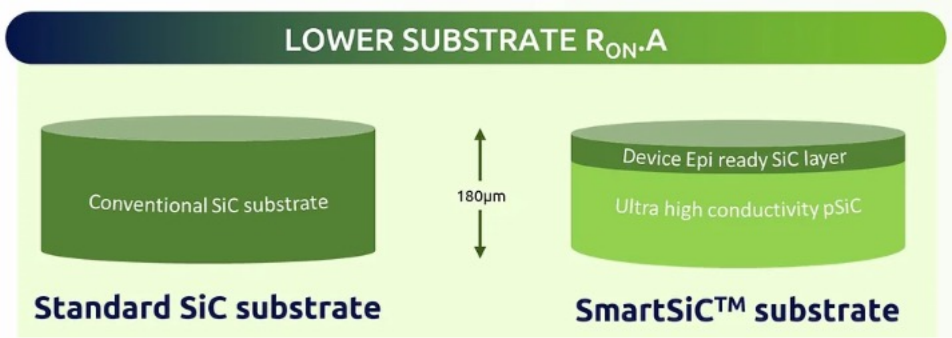
ENGINEERED SUBSTRATES

- Smart-cut enabled substrates can provide novel solutions:
  - **QST** (Qromis Substrate Technology) is CTE matched to GaN enabling thicker layers of GaN to be grown without bowing or cracking.
  - **SmartSiC** is already in production at Soitec. Bernin 4.
  - **SmartGaN** is in development and will consist of a high quality GaN layer on a silicon or non-silicon handle wafer.
  - It will address the power market above 1200V and high frequency RF.

QST Structure



SmartSiC



SmartGaN

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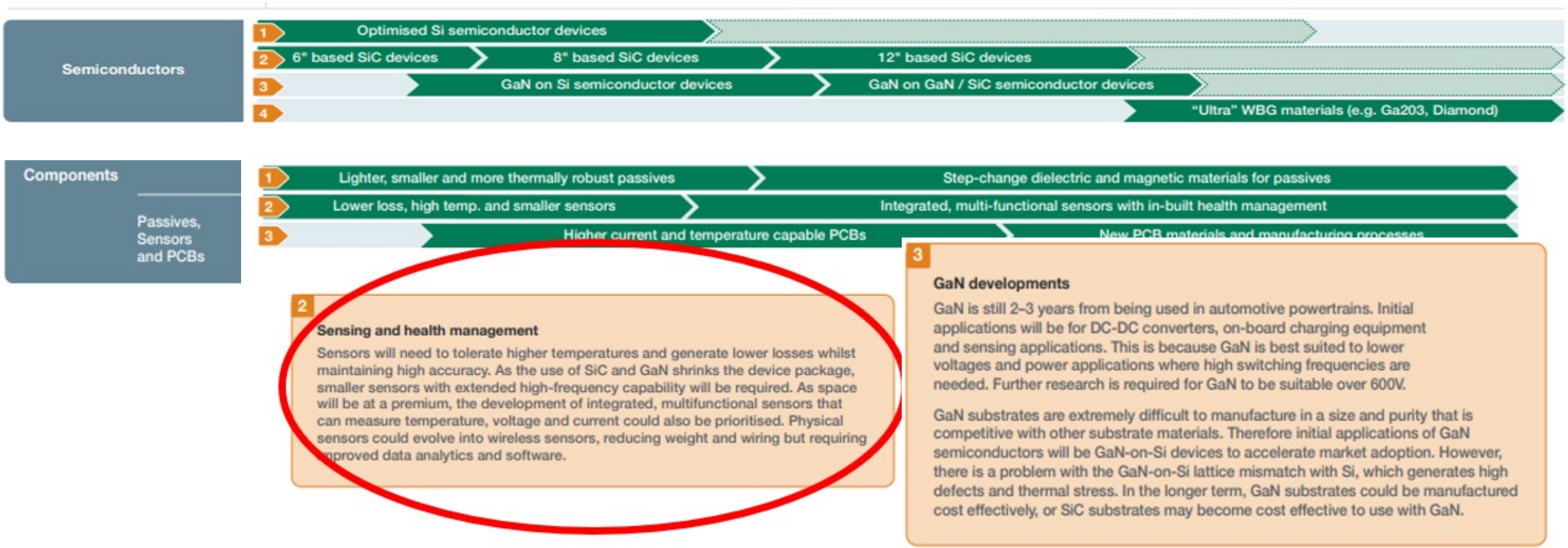
Substrate requirements for Power and RF are different

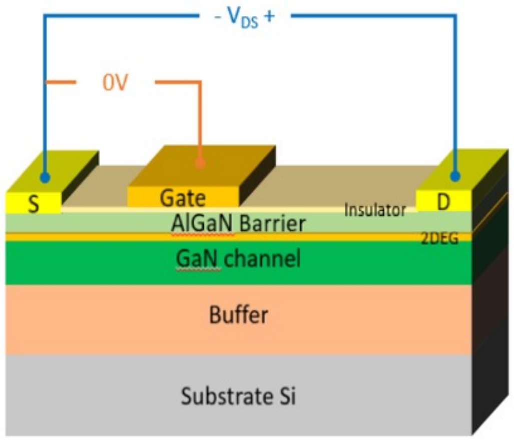
New Opportunities in Automotive (CAGR forecast 110% 2022-28)

APC Power Roadmap



How do we get to >1200V? - Transition from Lateral to Vertical Devices

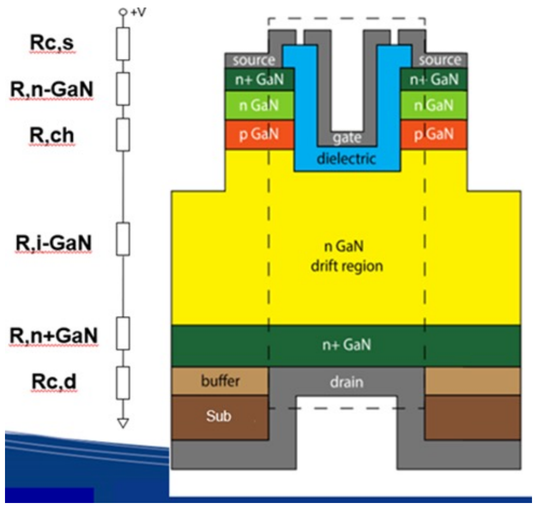
Lateral GaN HEMT



On-State(V_{GS} =0V)

- **Voltage scaling requires significant increase to chip area.**
- **More semiconductor real-estate required.**
- **HEMT structure based on 2DEG.**
- **Hetero-epitaxy is extremely challenging.**
- **Dynamic Ron is still an issue at High Voltage**

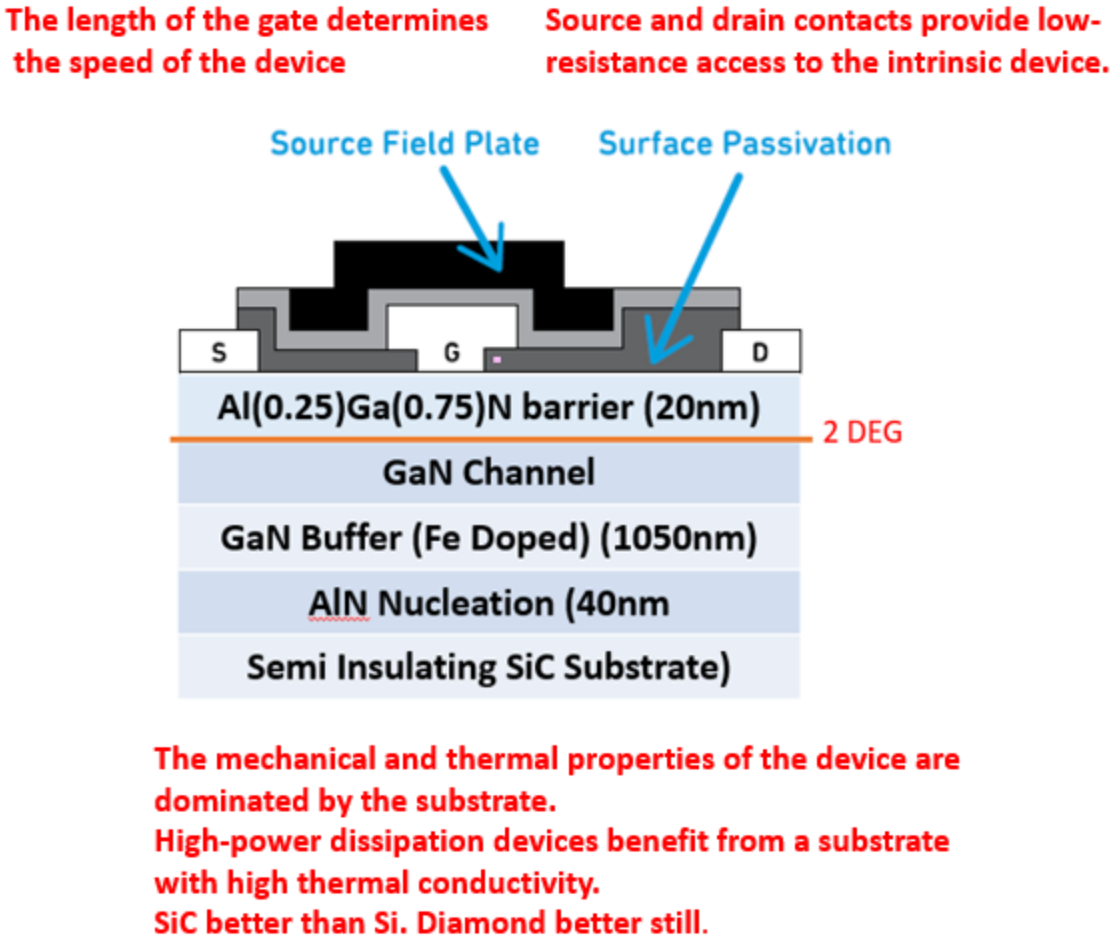
Vertical GaN Trench FET



- **Voltage scaling without increasing chip area.**
- **Breakdown voltage can be increased by increasing drift region thickness.**
- **Improved power density.**
- **Route to lower cost.**
- **Requires complex doping of GaN epi structure.**
- **Immature substrate technology (Bulk GaN)**

RF GaN Market

- RF market matured ahead of Power.
- Market dynamics different to Power (IDM vs Foundry)
- 4” GaN on Semi-insulating SiC slowly transitioning to 6”.
- Slower growth projections (CAGR forecast 12% 2022-28)
- Compare this to power (CAGR forecast 49%)
- Traditional markets (Telecom, Defence, Satcom).
- Difficult to displace incumbent Si and GaAs device technologies.
- Challenging for cost to compete against mature supply chains.
- Needs to provide performance advantages and compete at system level for cost.

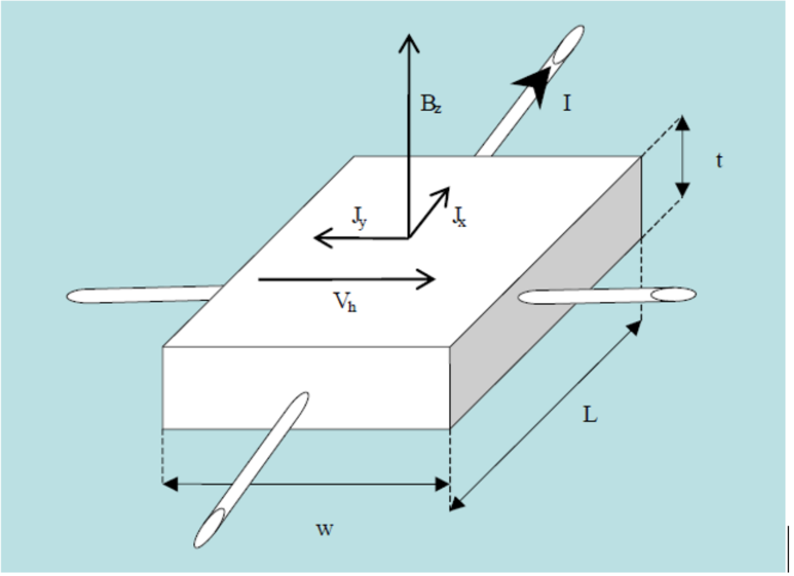


New Applications For GaN RF

- So where is GaN winning out?
  - Applications where it offers performance advantages – Increased bandwidth, Improved PAE, Improved thermal conductivity and ruggedness, Smaller form factor, Radiation hardness.
- GaN devices can be operated at much higher voltages than competing RF technologies (Si and GaAs). GaN can therefore produce more RF power in a given die area than any other semiconductor material.
- Telecoms - for RAN applications the TCO is impacted by ~40% of the energy consumption coming from the RU (radio unit).
- This impact will increase with the evolution of cellular technology as data loads and energy consumption grows.
- For satellite applications radiation hardness is highly desirable whether for PSU, motor-drives, sensors and RF PAs for satellite based 5G (Space X).

New Applications in Ultra High-Sensitivity Current and Positional Sensing

The Hall Effect.



$V_H = K_H.B.\ I$

Where

The sensitivity (K_H) of the sensor is given by $K_H = 1/t.n.e$ where:

t = thickness,

n = electron concentration

e = electron charge.

- 2DEGs are orders of magnitude thinner than silicon CMOS Hall effect devices and have higher carrier concentrations.
- They are therefore able to provide far higher resolution magnetic field measurements over a wide range of operating environments.
- Other significant benefits of GaN’s wider band gap include radiation hardness and high temperature tolerance which makes such devices suitable for harsh environments including space and high radiation, high-temperature applications.

Summary and Takeaways

- GaN is no longer a material of the future but very much of the present.
- It would have been so much better if we'd had a cost effective bulk substrate 30 years ago (like SiC).
- However, bulk GaN and Engineered GaN substrates could be game changing (but there's still a way to go).
- GaN will become more cost effective (especially at the system level) as supply chains mature.
- This will enable it to compete with incumbent technologies in both Power and RF as well as new applications where Si and GaAs can't compete.

Thanks For Your Attention