

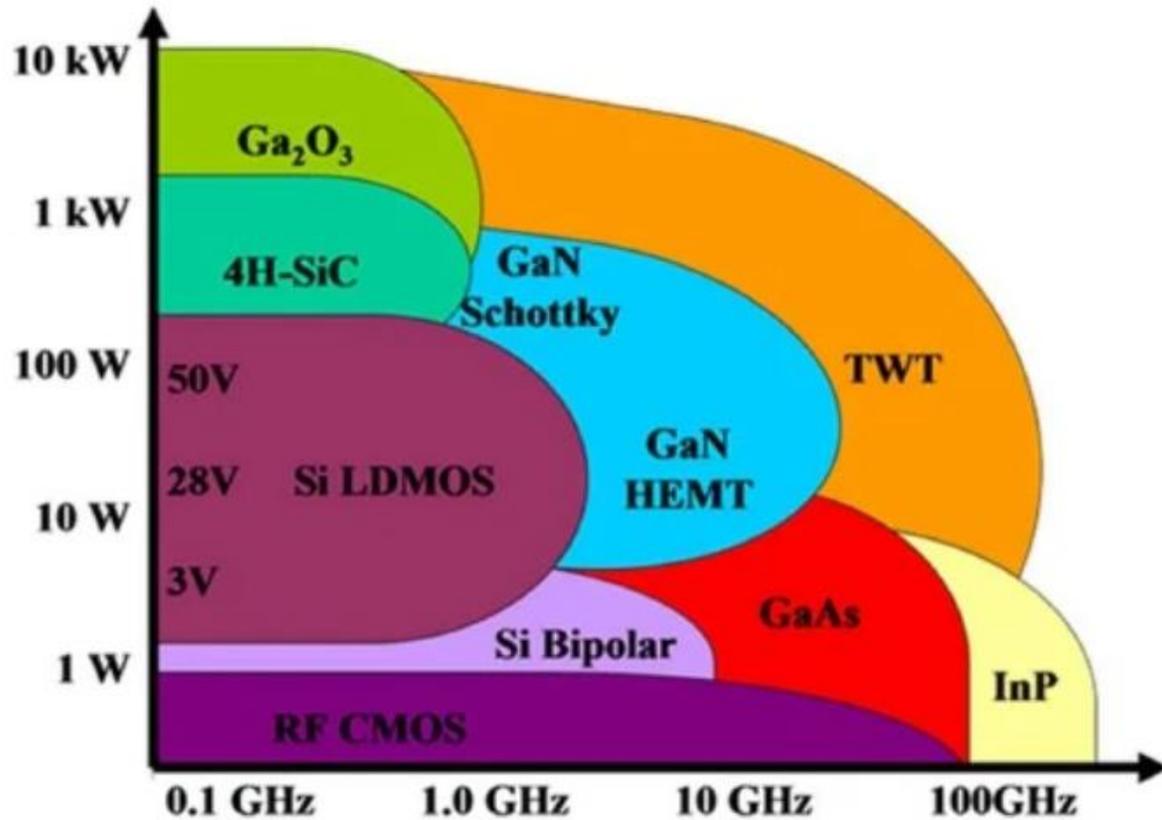
Building better gallium oxide devices via HVPE

April 2023

Heather Splawn

Applications for Ga₂O₃

Ga₂O₃ is expected to address those applications requiring the highest power levels → Unable to be met by other semiconductor materials



J.Y. Tsao, et al, *Advanced Electronic Materials* 4 (2018).

Power Grid



Electric Ships



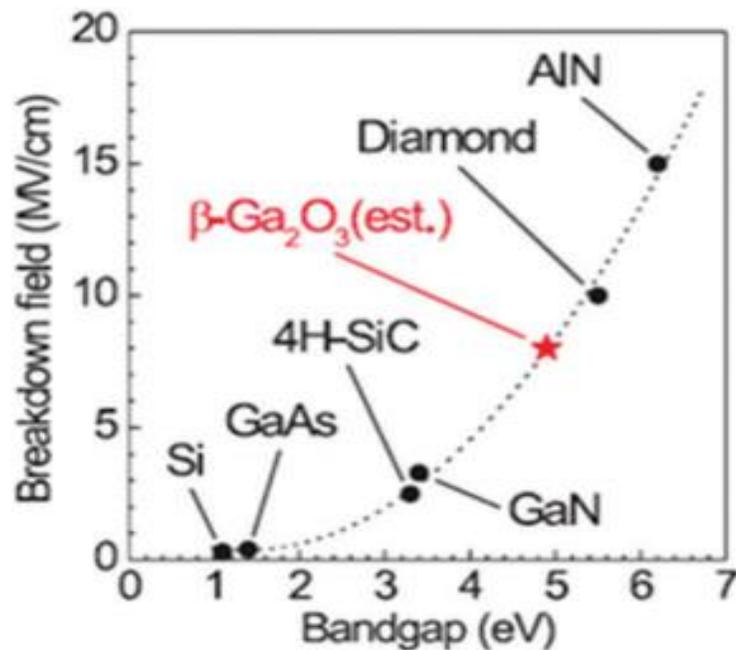
Electric Trains



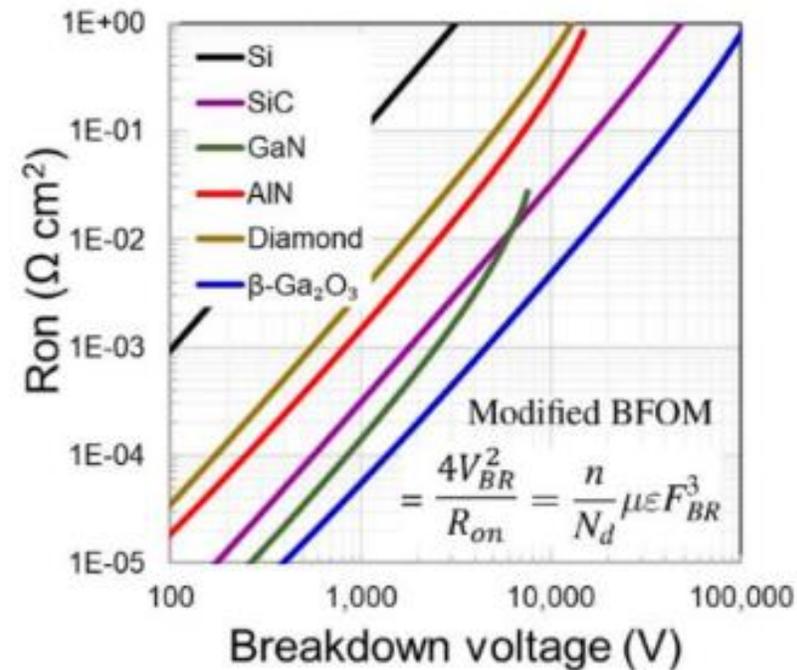
Why Gallium Oxide?

Excellent Material Properties—Fundamentals

- High breakdown field of Ga_2O_3 will allow for very efficient power switching devices
- The practical figure of merit, which takes into consideration the actual dopants used, shows that Ga_2O_3 is even better than other UWBG materials!



M. Higashiwaki, *et al*, *Semicond. Sci. Technol.* 31, 031001 (2016).

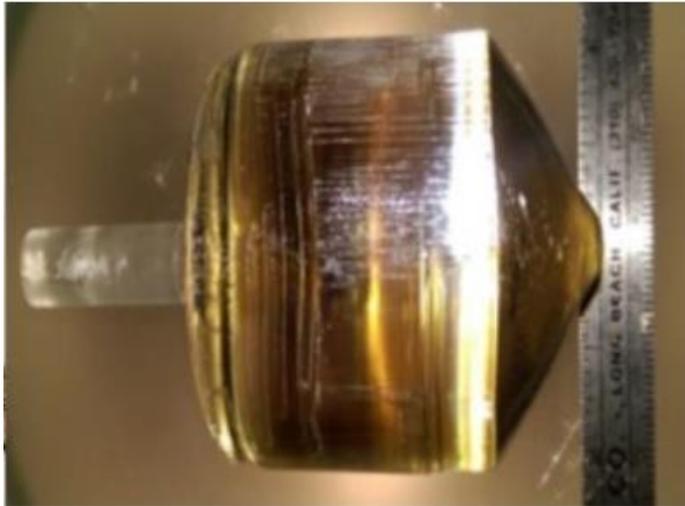


Y. Zhang and J. S. Speck, *Semicond. Sci. Technol.* 35, 125018, (2020).

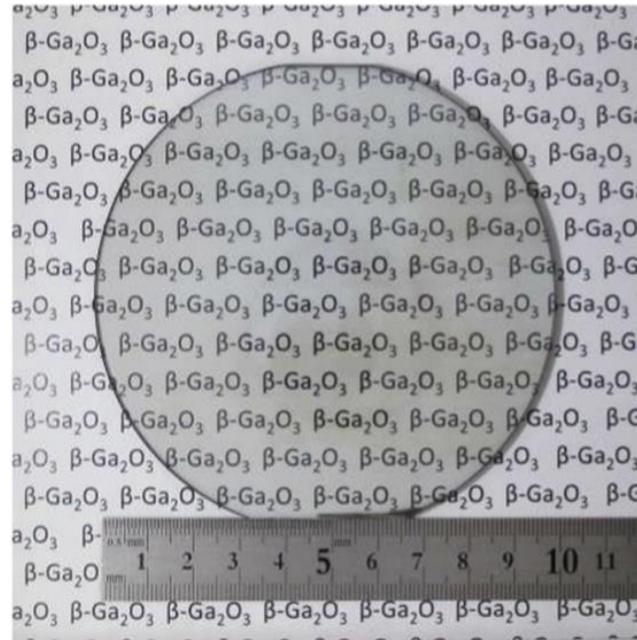
Why Gallium Oxide?

Excellent Material Properties—Practicality

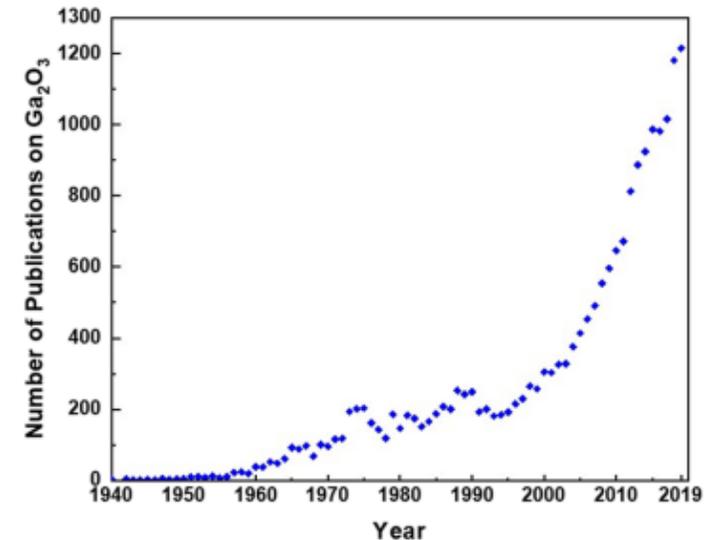
- Melt-grown 2" and 4" substrates are already commercialized and very high quality
- Epigrowth with well-controlled n-type doping demonstrated
- Device fabrication processes are straightforward
- Massive momentum—constant improvements in material and device results



50mm Ga₂O₃:Fe boule from Synoptics
*Blevins, *et. al.* CS MANTECH 14.2 (2017).



Commercially available 4" wafer from NCT



Rapid increase in interest due to promise of the material system

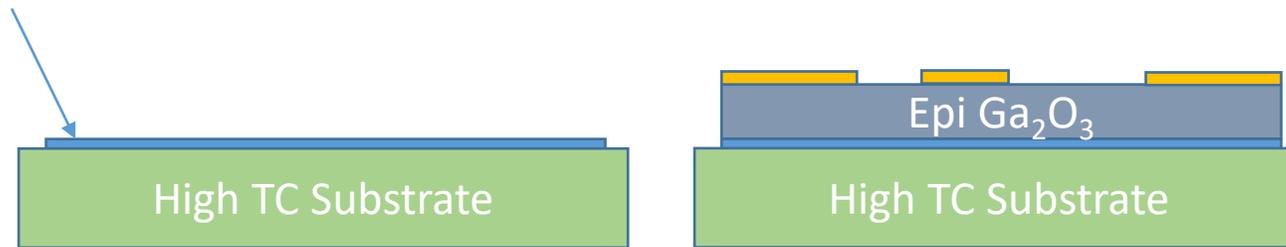
Why Not Gallium Oxide?

But wait, what about the thermal conductivity...

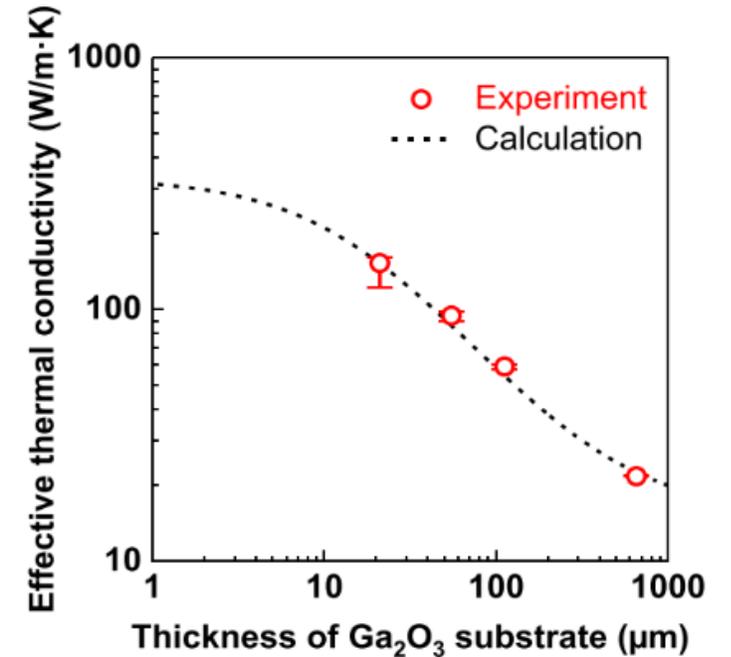
- Just a well-documented *engineering challenge*

Can we make an “engineered” substrate?

Thin device layer or epi-ready Ga_2O_3 layer



If so, the effective TC can be quite high!



Prior work from (001) Ga_2O_3 bonded to poly-SiC showing improved TC_{EFF} for thinned Ga_2O_3 layers

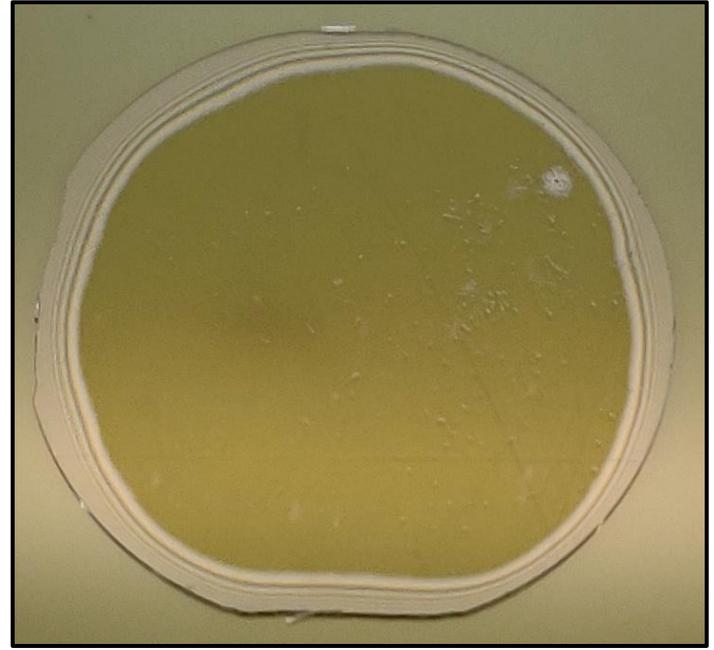
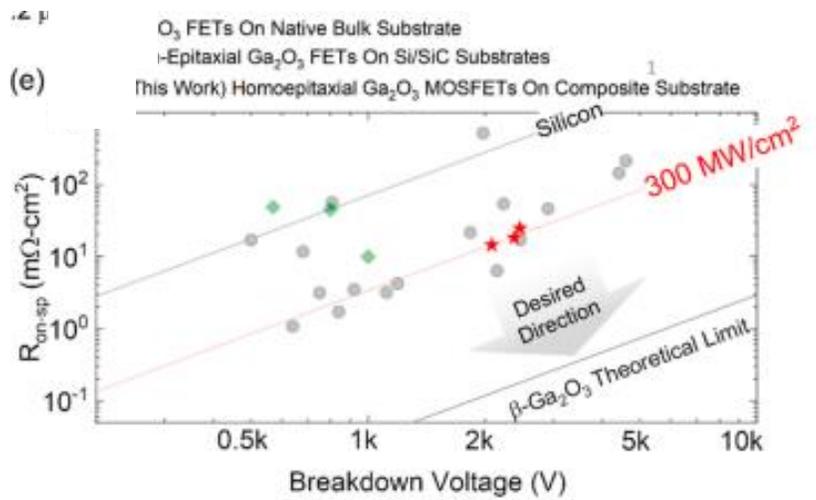
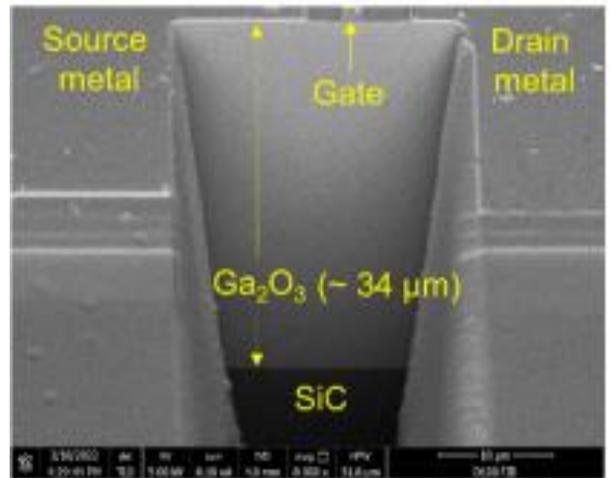
From: Lin *et al.* APL 114 032103 (2019).

Why Not Gallium Oxide?

But wait, what about the thermal conductivity...

✓ A solvable *engineering challenge*

Yes, we can make an “engineered” substrate!



1-inch Ga₂O₃-on-SiC (2”) After Bonding

We realized a 56% reduction in channel temperature!

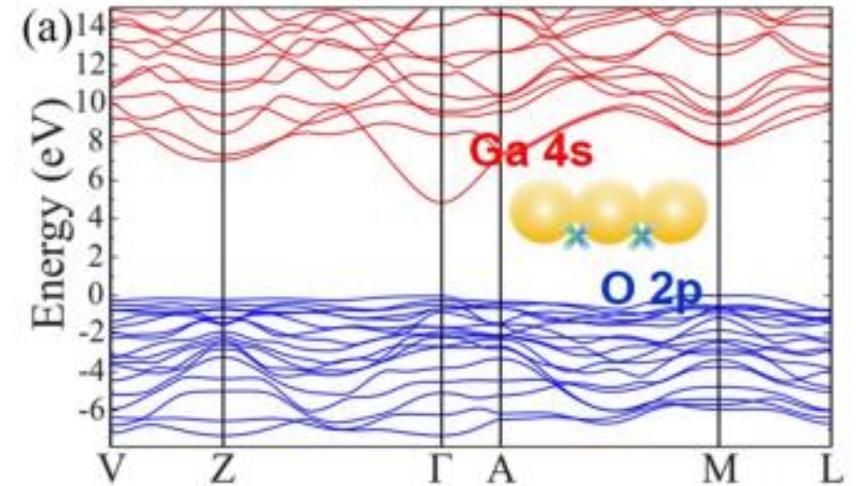
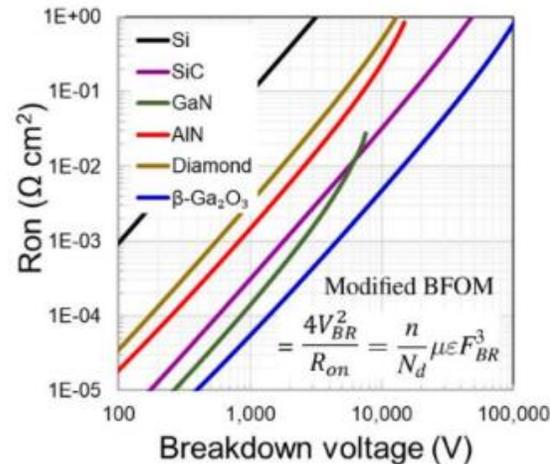
Y. Song, et al, ACS Appl. Mater. Interfaces 15, 7134 (2023).

Why Not Gallium Oxide?

But we don't have p-type doping...

- Indeed this is a problem for *bipolar devices*

But with such a high critical field, we can heavily dope our drift regions to avoid high on-resistance



Flat valence band means holes have near-zero mobility (self-trapped)

From: Zhang *et al.* APL Mater. 8, 020906 (2020).

Why use a bipolar device when unipolar will do?

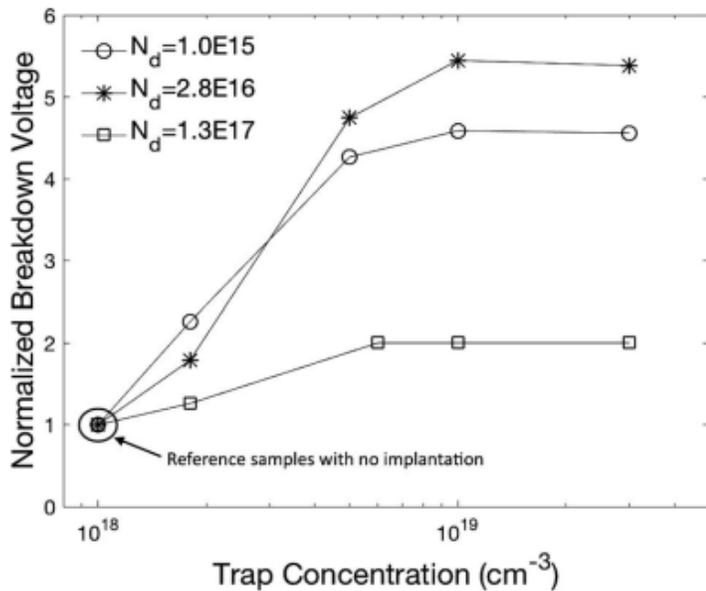
Y. Zhang and J. S. Speck, Semicond. Sci. Technol. 35, 125018, (2020).

Why Not Gallium Oxide?

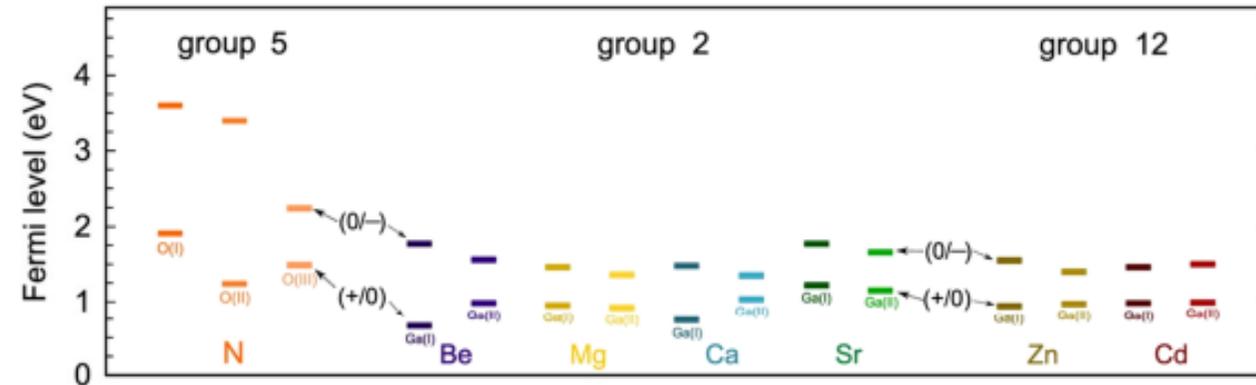
But we don't have p-type doping...

✓ Not a problem for *unipolar devices*

And we can still use acceptor doping for field management

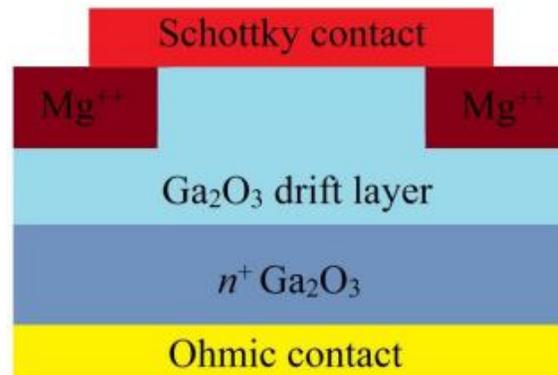


Sharma *et al.* ECS. J. SSST 8, Q234 (2019).



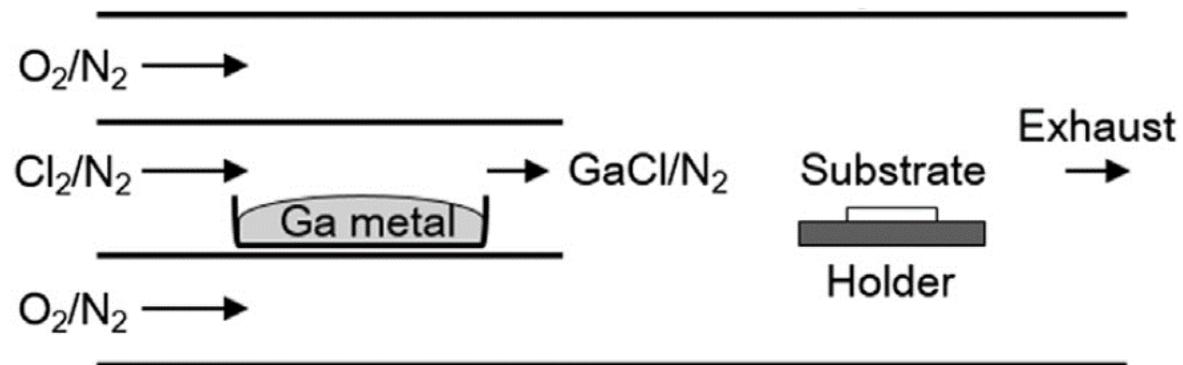
Many options for acceptor-like behavior in Ga₂O₃

From: Lyons, Semi. Sci. Tech. 33, 05LT02 (2018).



HVPE for HVPE

- For low-cost and high-performance
- High growth rates ideal for manufacturability
- Inherently cleaner than MOCVD
 - Chemically pure precursors
 - NO metalorganics containing carbon
 - Allows for high purity growth



HVPE for HVPE

Hydride Vapor Phase Epitaxy
for
High Voltage Power Electronics

Kyma HVPE



Kyma's 200mm diameter capable HVPE system

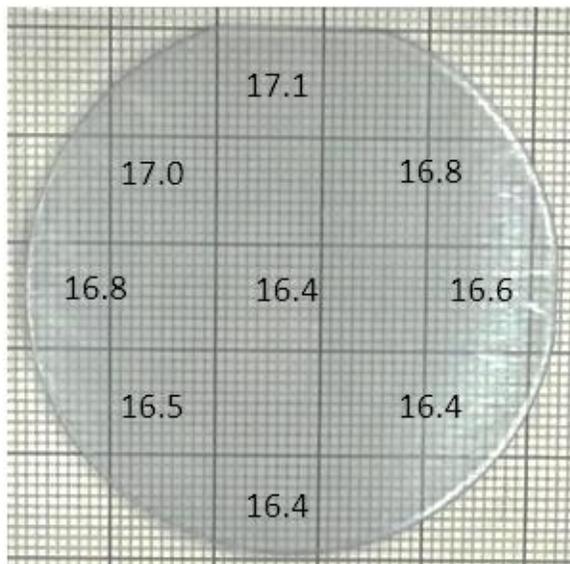
*Katharo*TM

Large Area HVPE is an enabling technology for
 Ga_2O_3 High Power Switching

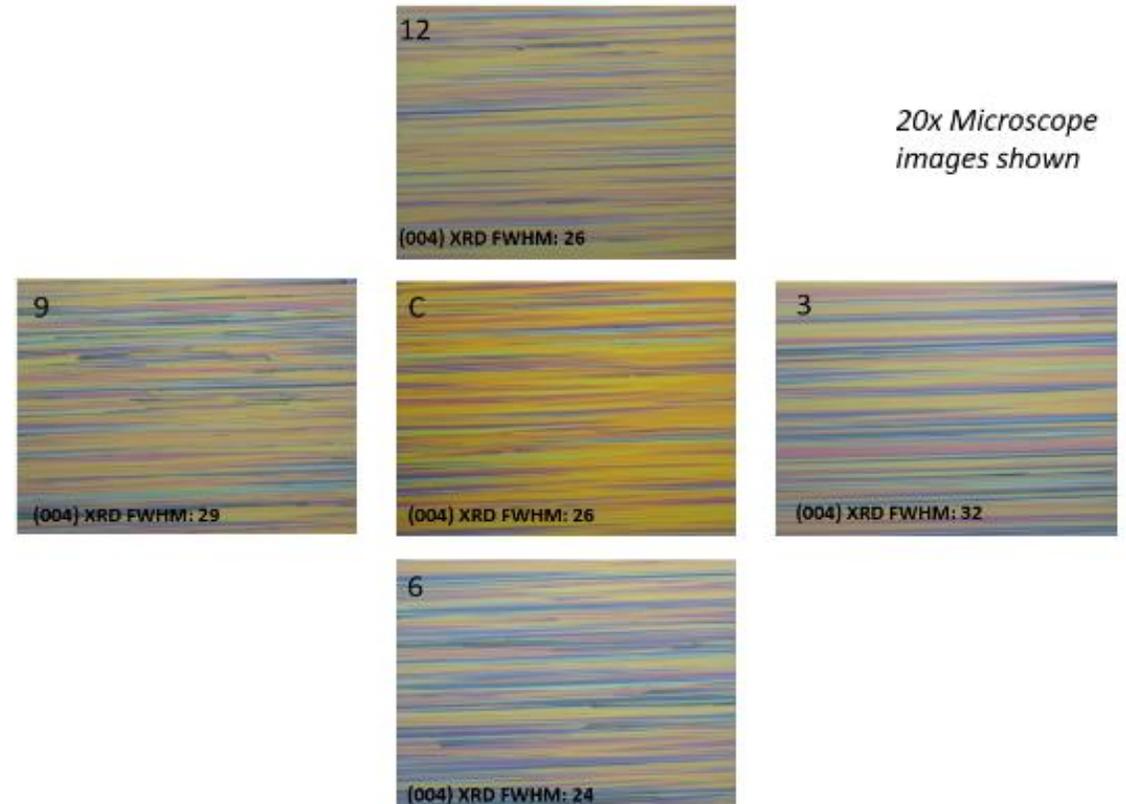
HVPE of Ga₂O₃

Why HVPE? For low-cost and high-performance

- Kyma's 100mm-capable HVPE allows for excellent doping control at epilayer thicknesses >20 microns (~8kV unipolar limit)
- Uniform doping and thickness demonstrated for 2", with XRD linewidths equal to substrate (~25-30 arcsec)



- **Thickness** over 2" : 16.7μm +/- 3%
- **N_d-N_a** over 2" from 2.7-5.8 x 10¹⁶

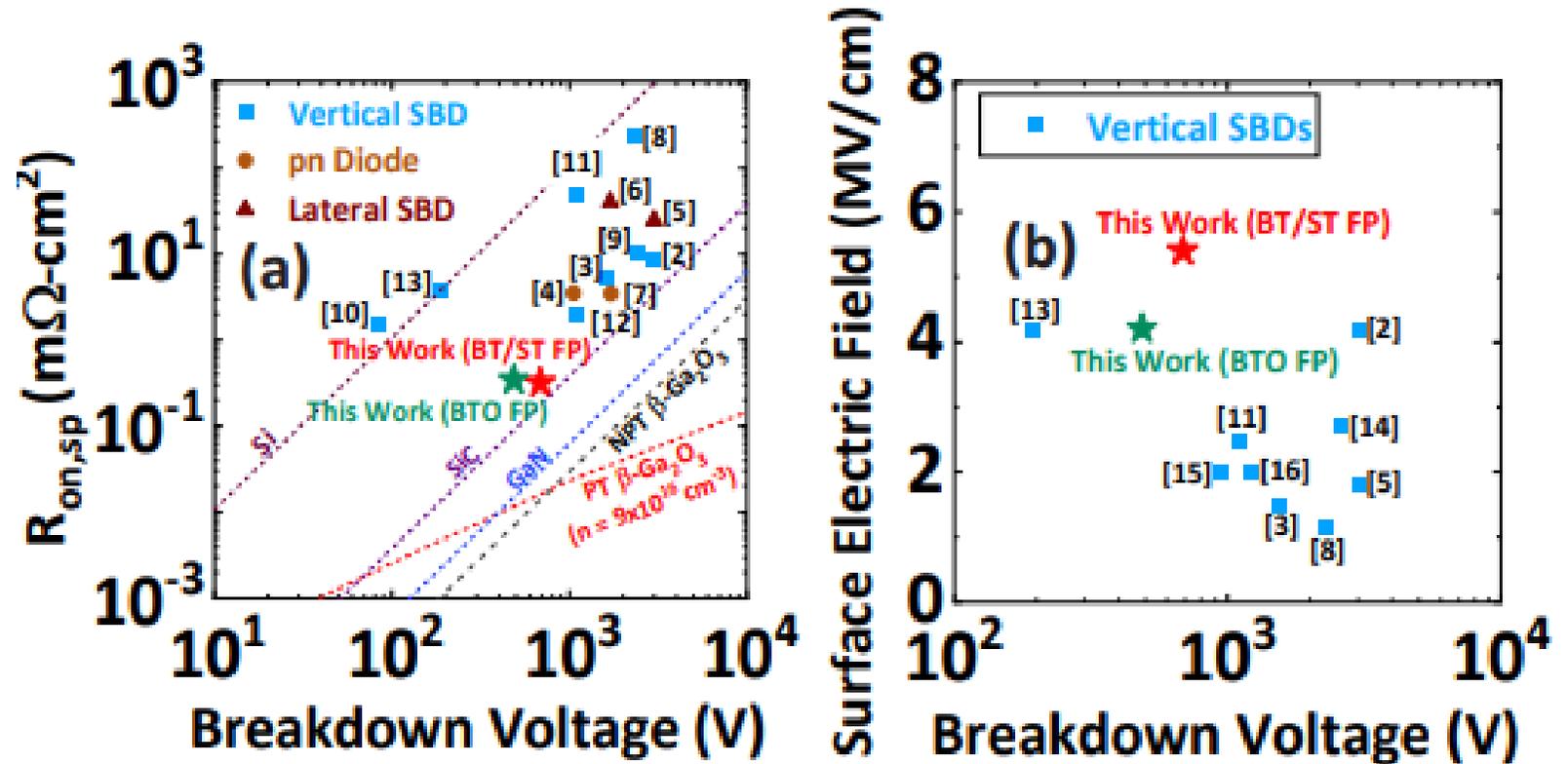


Kyma's HVPE in Devices

Kyma material used to demonstrate among the highest electric fields in any Ga₂O₃ device

AND

Resulted in BFOM
over 1GW/cm²



Breakdown field ~5.5MV/cm
BFOM >1GW/cm²

Additional Information

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