Perspective: Ga_2O_3 for ultra-high power rectifiers and MOSFETS

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Outline

- Introduction
- Why Ga_2O_3 needed ?
- Devices built on Ga_2O_3
- Future needs
- Conclusion

Introduction

- High voltage application - Wide band gap semiconductors used.
- SiC and GaN are present, but for power amplification application we need ultra-wide-band semiconductors.
- Thus, lies the requirement of Gallium Oxide.
- Initial device performance is promising but challenges exist.
- SiC $\rightarrow$ Use ? = Power flow control system.
- GaN $\rightarrow$ Use ? = 5G comm. and millitary application.
- Ga_2O_3 factors to consider -
  - Production capacity
  - wafer sizes
  - Substrate availability

[S. J. Pearton, F. Ren, M. Tadjer, and J. Kim, "Perspective: Ga2O3 for ultra-high power rectifiers and MOSFETS," Journal of Applied Physics, vol. 124, no. 22, p. 220901, 12 2018. [Online]. Available: https://doi.org/10.1063/1.5062841]

Why Ga_2O_3 needed ?

Properties and applications

- The β phase of Ga_2O_3 has-
  - large band gap (4.8eV)
  - breakdown field of 6-8 MV/cm
  - reasonable electron mobility
  - availability of native single crystal substrates
- SiC and GaN $\rightarrow$ High cost substrates.
- Ga_2O_3 $\rightarrow$ Low cost substrates because of melt like Si availability.
- Maximum v/g that a semiconductor can withstand = onset of avalanche breakdown created by impact ionization process.

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Why Ga_2O_3 needed ?

Comparasion of properties of SiC and GaN with potential wide bandgap semiconductors for power electronics							
Parameter	SiC	GaN	High-Al AlGaN	Ga_2O_3	Diamond	Advantage (Ga_2O_3)	Disadvantage
Bandgap(eV)	3.3	3.4	5.8-6.2	4.85	5.5	Larger means Higher critical breakdown field	
Critical breakdown field ($MVcm^{-1}$)	2.6	3.3	12.7-16	5 to 9	10	Larger than SiC or GaN	
Electron Mobility	1000	1200	310	250	2000		Lower Switching speed
Hole Mobility	90-120	120	~30	N/A	450		Absence of pn junctions
Thermal conductivity	370	130	320	10 to 30	2000		Low and anisotropic
Substrate size (in.)	8	8 on foreign substrate- Native still under development	3-4 on foreign substrate, 2 on AlN	6	1.5(larger on Si)	Competitive with SiC and expected to go lower	
Substrate cost/cm^2	~8.5	0.2-0.5 on Si, ~110 on native substrate	~110 on native GaN substrate	~215	~2.15x10^5 large single crystal	prices dropping rapidly	
Dopability	Good for both conductivity types	High ionization energies for acceptors	High ionization energies for acceptors	n-type from insulating to 10^{20} cm^{-3}; no p-type doping capability	n-type difficult due to large ionization energy of P		Absence of pn junctions
MOS technology	Nitric Oxide annneal	Developmental	Developmenta	Primitive	Developmental		Large gate swing and thermal
High Temperature(FOM)	0.36	0.1	0.86	0.01	0.06		Maor heat removal issues

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Why Ga_2O_3 needed ?

Applications

- Commercial Gallium Oxide device at present is Schottky barrier diode offered by Flosfia, Inc.
- Initial thrust is targeted towards DC/DC and DC/AC applications
- Some potential applications:
    - Electric vehicles $\rightarrow$ 600-1200V/5-10A $\rightarrow$ MOSFET
    - AC, induction cookers $\rightarrow$ 600V $\rightarrow$ IGBT
    - Electric vehicle power train $\rightarrow$ 500-1000V / 100-500A $\rightarrow$ IGBT

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Why Ga_2O_3 needed ?

Defects and Doping limitations

- Most Common contaminants - H,Li,B,C,N,O & Si
- Si $\rightarrow$ Amphoteric species $\rightarrow$ act as donors in GaAs sites.
- EPR and ESR have been used to identify shallow donor, acceptors and self trapped holes.
- In terms of device requirement $\rightarrow$ doping concentration should be from lowest background n type concentration possible to as high concentration as possible.

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Ga_2O_3 Devices

Ga_2O_3 **Rectifiers**

- Schottky rectifiers made on wide band gap semiconductors have fast switching speed.
- In SiC, a wide variety of edge termination methods adopted.
- Common edge termination techniques:
  - Field plate edge termination
  - P-Guard rings
  - Junction termination extensions

Konishi in paper obtained a reverse breakdown voltage of 1KV.

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[K. Konishi, K. Goto, H. Murakami, Y. Kumagai, A. Kuramata, S. Yamakoshi, and M. Higashiwaki, "1-kV vertical Ga2O3 field-plated Schottky barrier diodes," Applied Physics Letters, vol. 110, no. 10, p. 103506, 03 2017. [Online]. Available: https://doi.org/10.1063/1.4977857]

Ga_2O_3 Rectifiers

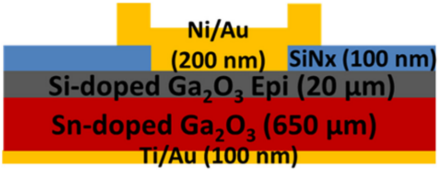

Figure: Schematic cross section of rectifiers with front side

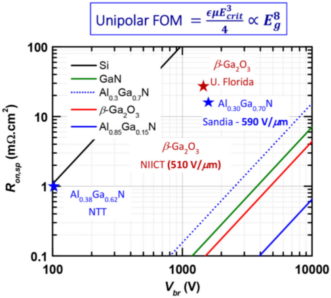

Figure: Plot of on-state resistance for vertical rectifiers on Ga_2O_3 and AlGaN, along with the theoretical curves for different semiconductors

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Ga_2O_3 Devices

Ga_2O_3 **MOSFETs**

- Efficiency of SiC MOSFET is attributed to -
  - High critical field
  - Wide band gap
  - ambipolar doping
  - long minority carrier lifetime
- Finds use in 600V market space.
- employed in rf domain as a result makes use in mobile phones as well.
- Most promising design → Fin based vertical JFET.
- Most are of depletion type
- SiC - Schottky diode reached commercialization nearly 10 years ahead of MOSFET.

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Future Needs

- Commercial application for wide band gap power electronics include
  - wireless charging
  - more efficient data centres
  - more efficient data drives
  - electric vehicles
- To find application in power switching, following areas need sustained deevelopment
  - Epitaxial growth
  - Improved ohmic contacts
  - Thermally stable Schottky contacts
  - Enhancement mode operation
  - Reduction of dynamic R_{ON}

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Conclusion

A technology's Figure of Merit grade often serves as a summary of its performance, whereas in particular on-resistance is frequently used to assess the cost/performance ratio. The ideal device is determined by a number of technical as well as commercial considerations, and Ga_2O_3 is both aided and hindered by the progress of GaN and SiC devices. The voltage ranges covered by GaN devices are predominant from tens to hundreds of volts, while SiC devices are found from around 1 kV to few kilovolts. Whereas SiC devices are now at and will extend down to 600 V, future voltages for GaN devices will range to 3300 V. At high voltages, Ga_2O_3 may assist these materials rather than replace them.

Thank You