Perspective: Ga_2O_3 for ultra-high power rectifiers and MOSFETS

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by

Saurabh Suman
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Under the guidance of
Dr. Brajesh Rawat

DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY ROPAR

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SAURABH SUMAN

Entry No. 2023EEM1028

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Abstract

Gallium Oxide (Ga_2O_3) is becoming a vital semiconductor because of its large band gap, controlled doping levels and the availability of inexpensive substrates. It's applications includes power conditioning system consisting of pulsed power in avionics and electric ships, solid state drivers for heavy electric motors and in control electronics. Due to its large bandgap, it helps in saving energy as well as cost. $\beta - Ga_2O_3$ also has larger electric field as compared to Silicon carbide (SiC) or Gallium Nitride (GaN). Reverse biased voltage of over 3kV has been observed. Majority of the MOSFETs fabricated on Ga_2O_3 are of the depletion mode except for a few being enhancement mode. Having all these features, this also comes with some limitations one of them being low thermal conductivity when device is transferred to another substrate. The report focuses on properties of this material, transport physics, thermal conduction, doping capability and device design all of which gives an insight of current limitation and future areas of improvement. After all Gallium oxide may support but cannot substitute Silicon carbide and Gallium Nitride.

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Chapter 1

Introduction

For power switching and power amplifier application, we need materials with wider bandgap than that of the SiC and GaN. Wide band gap materials is emerging as a new area of focus. Ga_2O_3 thus becomes an important material in this perspective. These ultra wide band gap semiconductors perform much better in its initial phases but challenges exist. Those materials which could come into practice includes Al-AlGaN and Ga_2O_3 majorly. Considering the application, performance and design of SiC and GaN are such that they have their own requirement but there are certain semiconductors which have outperformed these as per application.

Going down the history we have seen that it takes almost about 35 years from conceptualization to actually come into practice. Such a time period is required in this sector because it needs development, growth, processing and device design platforms. GaN went through a long phase as it was helpful and also got its funding in military field. It is used in radar, electronic warfare and communication systems. It also finds space in 5G communication. Regarding SiC, for decades it has bee serving in power flow control systems.

Regarding Ga_2O_3, there are a multiple factors to consider before implementing it. Some of which include production capability, wafer sizes, substrate availability and manufacturing. Diamond, AlN and BN could help in achieving the purpose but is unhelpful due to high cost and immature doping Another wide band gap material which is developing is Al-AlGaN, which is suitable for lateral power devices. But is limited due to large area, cheap native substrates and lower electron mobility.

In this report [1] we are attempting to see whether Gallium oxide (Ga_2O_3) can be used as a substitute for Silicon Carbide (SiC) and Gallium Nitride (GaN) as Ga_2O_3 has ultra wide bandwidth for finding application in power switching and RF power applications. High thermal resistance is a major problem in implementing Ga_2O_3. Another issue is the absence of p-type conductivity when doped through acceptors. Thus, limits the type of device structure which can be realized. To overcome it, we need effective thermal management approaches.

Chapter 2

Why Ga_2O_3 ?

2.1 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

The devices built using SiC and GaN have higher cost and the availability of substrates are limited. Apart from these substrates of these devices can't be grown easily from melt like Si whereas for Ga_2O_3, it can be easily done through this process.Figure 2.2 shows how Ga_2O_3 crystals are obtained from melt. For SiC and GaN, it is grown from high cost substrates thus has a limited advantage. Seeing from the point of application, there are may properties which can be looked upon and guarantee why Ga_2O_3 is useful in wide band gap applications.

For a semiconductor device to perform well, it should sustain a voltage equal to the avalanche breakdown which is defined by the impact ionization process. The process is characterized by the impact ionization coefficient defined for electron and holes in a way that the no. of electron hole pairs generated while traversing through the depletion region for a distance of 1cm in the direction of electric field. There are difficulties in the measurement of these parameters such as defects in the semiconductor prevents the smooth measurement, also the non uniform electric field create difficulties.

TABLE I - Comparison of properties of SiC and GaN with wide band semiconductors for power electronics.

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

Figure 2.1 showing what is illustrated in the table in graph form. Thermal management is also an issue which it faces. For example, consider GaN RF devices that are operated at temperatures greater than the temperature on the sun's surface. GaN HEMTs (High electron mobility transistors) are capable of driving at much higher speeds than compared to Si MOSFETs. This faster switching speed is related to the parasitics involved. As GaN matures, the minimization of these parasitics helps in the maximization of speed. The role of GaN in power applications remains unaffected even when carrier mobility in the bulk of Ga_2O_3 is lower than others. This remain unaffected because the usefulness which is given by the FOM depends majorly on the Breakdown Electric field rather than mobility.

Finally, looking at all these parameters it can be understood that Si, SiC and GaN enjoys a lot of advantages in terms of process maturity but also faces the challenge of ultra wide band gap materials. In case of βGa_2O_3, the availability of large and inexpensive crystal comes on a positive note. Figure 2.3 shows how Diamond and Ga_2O_3 crystal being of the same size saves

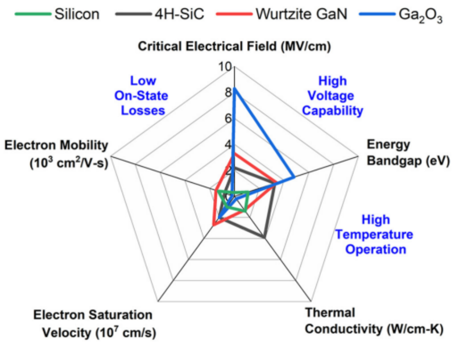

Figure 2.1: A pentagon diagram showing critical material properties important to power semiconductor devices

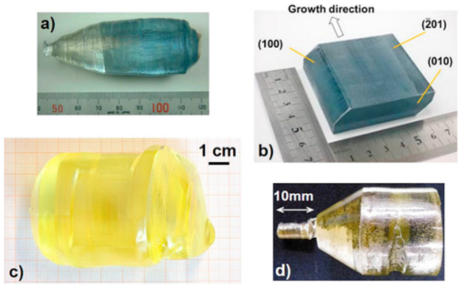

Figure 2.2: Bulk βGa_2O_3 crystals obtained from melt by the following methods-(a)Optical float zone (b)Edge fed defined growth (c)Czochralski (d)Vertical Bridgman

the cost.

From Table I, under Ga_2O_3 inside the dopability category, it can be seen that there is no p-type doping. This happens because hole concentration goes beyond what is required and is available at higher temperature. Further, self trapping holes phenomenon occurs which decreases effective p type conductivity, resulting in lower mobility.

Talking about the commercial availability of these materials,

- Tamura Corporation provides bulk samples
- NCT commercialized Ga_2O_3 epilayers grown from MBE(Molecular Beam epitaxy) and HVPE(Halide vapor phase epitaxy)
- Synoptics is putting hands on small diameter Fe-doped bulk wafers.
- Apart from all these, at present, Schottky barrier diode from Flosfia, Inc.(Kyoto University) is made avvailable in engineering quantities.

These devices are made of α-Ga_2O_3 produced via spray assisted mist CVD, which uses a simple precursor of gallium acetylacetonate soaked in water that is then delivered to the heated substrate as mist particles by a carrier gas. For SiC power devices, it holds a market cap of US 1.4 billion dollar by 2023 with a CAGR of 30 $\%$ between 2017 and 2023. The main market under this consists of inverters, DC-to-DC converters, PFC power supplies, photovoltaics, motor drives, wind and rail.SiC is being used in many of the places such as in PFC and PV applications but MOSFET's use in automotive application is taking up a rise. A 3-phase 10KW PFC

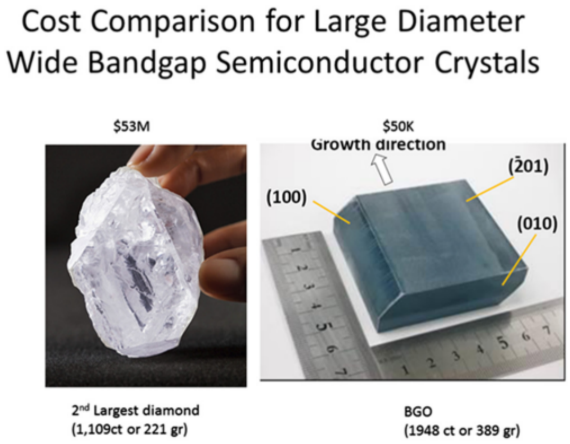

Figure 2.3: Cost comparison of large diameter diamond and Ga_2O_3 crystals

build upon SiC MOSFET which converts an input voltage of 230V to 700V. There are some performance parameters to be looked upon. Some of them are as - total hamonic distortion which ideally should be 0%, power factor whose idseal value is% and efficiency which should be 100%.

Now, a basic idea by a system manufacturer would be to make a cost effective system. As we

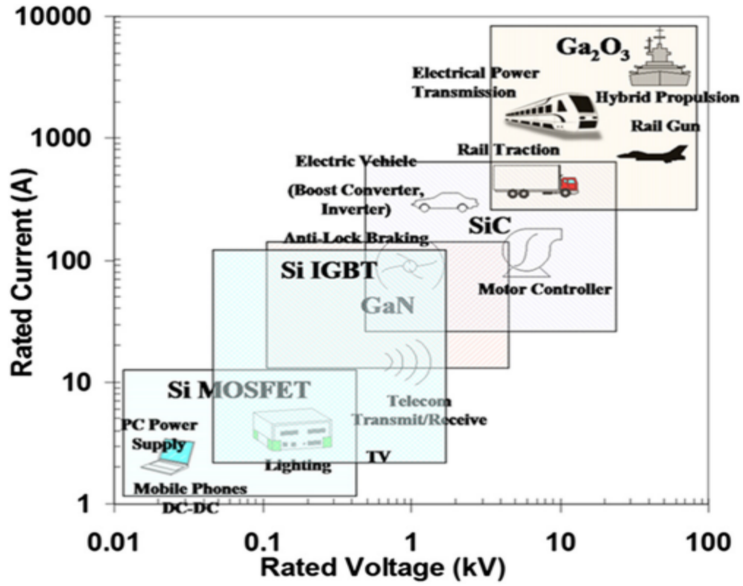

Figure 2.4: Application of different materials in term of voltage and current required.

have looked upon for SiC, GaN is used for lower voltage applications. From all these discssions carried out above, it is clear that before moving to any new technologies, there are certain things to look upon such as-

- Does it have new capability?

- Is it comfortable to use without any difficulty?
- Is it pocket friendly?
- Is it reliable?

Having discussed about already existed materials which are in industry, let's now consider our case for Ga_2O_3. It is targeted mainly for DC/DC and DC/AC applications. For applications that require power switching operating voltage has its upper limit set by the Breakdown electric field strength. Total loss in energy is determined by the resistive and capacitive loss. Resistive loss occurs due to ON state current conduction and capacitive loss occurs during dynamic switching. As already discussed, it is the millitary application that is leading to the success of Ga_2O_3. Table II lists some commercial and infrastructure applications. Precisely looking upon SiC and GaN devices, it falls mainly in 3 categories : 300-1200V with a current rating of 5-100A, 500-1200V with a current rating upto 500A, 1000-6500V with a current rating of 500-800A. Having these capabilities, still Ga_2O_3 is preferred because of low thermal conductivity and absence of p type doping. An HVDC transmission is used instead of three-phase AC network. Advantage that comes into picture by employing this mechanism is, it has a power rating of 100MW and in some cases from 1000-3000MW as per need. Another advantage of HVDC is that we can control the power flow accurately both in terms of direction and power level. Another reason why HVDC being preferred over AC is lower setup cost, low loss, controllability , etc. It doesn't impact the environment as the transmission lines used are small and for same power to be matched it needs less space. Thus have many potential reasons to be implemented. One difference that it has the capability to control active power.

2.2 β-phase versus α-phase

Due to its easier epitaxial connection, α-Ga2O3 is the second most researched polytype after β-phase, making heteroepitaxial development on sapphire substrates easier. The nearest lattice-matched polymorph with sapphire's corundum structure is α-Ga2O3. The use of multiferroic and magnetoelectric phenomena is made possible by the potential for alloying with $a - Fe_2O_3$ and $a - Cr_2O_3$. On orientated substrates, the rhombohedral α-phase develops epitaxially. Additionally, it should be able to create useful heterostructures or adjustable bandgaps by alloying, considering their structural resemblance to other wide bandgap materials as ZnO and AlN. Since

Table 2.1: Voltage and Current ranges for high power electronics applications

Classification type	**Application**	**Voltage and current range**	**Si device type**	**SiC, GaN, Ga_2O_3, device type**
1	Electronic vehicle charger	600-1200V/5-100A	MOSFET/IGBT	MOSFET, HEMT, rectifier
2	Appliances(AC, induction cookers)	600V/5-10A	IGBT	MOSFET, HEMT, rectifier
2	Data center HVDC	800-1200V/25-250A	MOSFET/IGBT	Vertical MOSFET, rectifier
2	Electric vehicle power train	500-1000V/100-500A	IGBT	Vertical MOSFET, rectifier
3	Photo voltaic inverters, wind farms	1-6.5kV/0.5-205kA	IGBT	Vertical MOSFET, rectifier
3	AC drives/Traction	2.5-6.6kV/0.5-8kA	GTO Thyristor	GaN or SiC IGBT

the α-Ga_2O_3 an a-lattice parameter mismatch that is moderate in-plane. Upon reaching sufficiently high temperatures, all other polymorphs become metastable and change into the β form; hence, only the melt may be developed into beta form of Ga_2O_3. In a practical sense Only the β-polytype is anticipated to have a big part. Nonetheless, the alpha phase does possess a variety of rewards.

2.3 Defects and doping limitations

Among all the elements found in nature, there are elements with light mass such as H, Li, B, C, N, O and Si. These are potential elements to create impurity in semiconductor devices during the process of device processing and growth of crystals. Amorphous elements such as Si which can act as donor and acceptor both based upon which sites it occupy during doping. In GaAs it occupies the Ga sites and thus act as donor atoms creating n-type semiconductor. The concentration of Si in such crystals is about $10^{-18}cm^{-3}$. Si also occupies As sites and act as acceptor for higher concentration GaAs materials.

For identifying self-trapped holes, acceptors and shallow donors, Electron spin resonances(ESR)

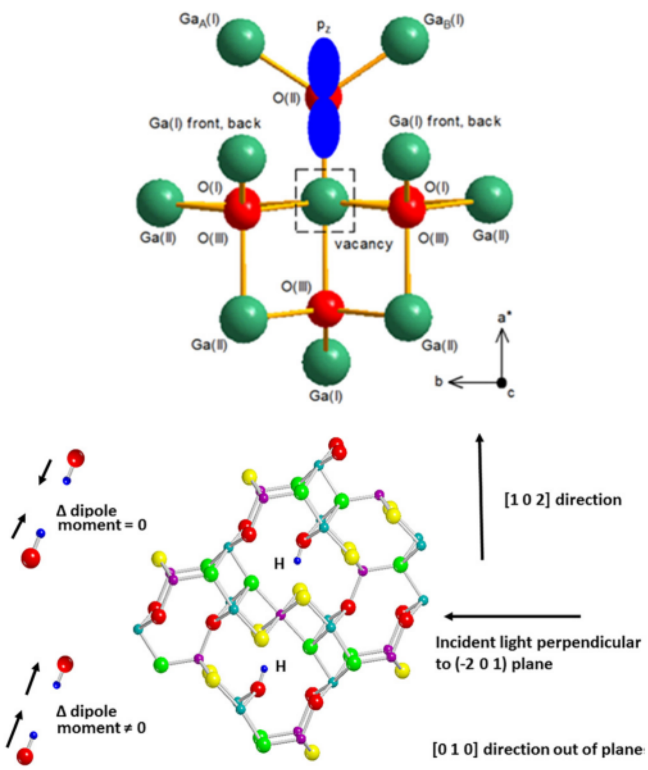

Figure 2.5: Model of the doubly ionized gallium vacancy in β-Ga_2O_3 (Top). Model of V_{Ga}^{-}H, the dominant OH center in Ga_2O_3 (Bottom)

and Electron paramagnetic(EPR) are used. There are two different Ga sites consisting of tetrahedral and octahedral point symmetry in monoclinic lattice form of β-Ga_2O_3 and there is no ambiguity in the assignment of this defect. The model presented in Figure 2.5 (Top) illustrates how the V_{Ga}^{-} acceptor forms when it traps a second hole at the O(III) oxygen, which is located opposite the hole at O(I), which is the top oxygen ion. The gallium vacancy is located at the nearby sixfold Ga(II) site, whereas the hole is on a threefold oxygen ion at an O(II) site. Hydrogen's well-known ability to passivate semiconductor faults and dopants has a well acknowledged effect on semiconductor technology. Hydrogen has a significant impact on the electrical characteristics of oxide semiconductors because it may generate shallow donors and passivate deep compensatory defects. For instance, it was discovered that in ZnO, hydrogen produces shallow donors. In oxide semiconductors, the charge carriers have the ability to self-trap or delocalize, forming tiny polarons. The major hydrogen-induced defect in β-Ga_2O_3 is created when intrinsic wafers are annealed in the presence of atomic hydrogen. This defect consists of two atoms of hydrogen locked within the gallium vacancy site, also known as the relaxed V_{Ga}^{-} 2H center, which can function as a hydrogen source or sink. At 3437 cm^{-1}, they discovered an infrared vibrational band peak for this faulty location. Fig.2.5 (bottom) displays the center's microscopic depiction.

According to the requirement of the device, The n-type doping varies from lowest ($< 10^{16}cm^{-3}$) background to highly possible contact regions($> 10^{19}cm^{-3}$). Construction of pn junction is eliminated because p type material cannot be build as self trapped holes eliminates the p-type conductivity.

Chapter 3

Ga_2O_3 Devices

3.1 Ga_2O_3 Rectifiers

Rectifiers made on the wide band gap semiconductors such as schottky rectifiers have high switching speed, improves the efficiency, Forward voltage drop is low and is able to operate at high temperatures. βGa_2O_3 built on EFG has shown potential performance. It has Reverse breakdown voltage is very high and R_{ON} is low. As of now, the presence of defects and breakdown in the depletion region limits the performance of Ga_2O_3. To even up the distribution of electric fields surrounding the rectifier contact periphery in SiC rectifier devices, many kinds of edge termination techniques have been used. With only a few cases of field-plate dismissal, the situation for Ga_2O_3 is significantly less well-defined.
Without any edge termination methods [2], about 1kV of reverse breakdown voltage is seen, miximizing upto 2.4kV. The maximum value is obtained when a high quality substrate is layered with thick epitaxial layer. The rear surface could have had some pre-treatment in order to improve conductivity and reduce contact resistance. This might involve ion implantation of donor dopants, plasma exposure, or ozone cleaning. Fig.6 (top) shows the device structure and the bottom one shows reverse I-V characterstics. A junction barrier Schottky (JBS) diode design, in which a pn junction is used to cause the drift layer to deplete away from the surface under reverse bias, may be able to achieve even greater breakdown voltages. By depositing Li-doped NiO_2 or Cu_2O on $Ga_2O)3$ and $Ga_2O)3$ on 6H-SiC, pn type heterojunctions in the case of $Ga_2O)3$ have been established. $\alpha-(Rh,Ga)_2O_3$ is an additional possibility. Compared to a Schottky diode, the pn junction's turn-on voltage is larger for broad bandgap oxides like Cu_2O. For Schottky diodes, CuO_2 or CuI might be used as the guard ring. Fig. 2 illustrates

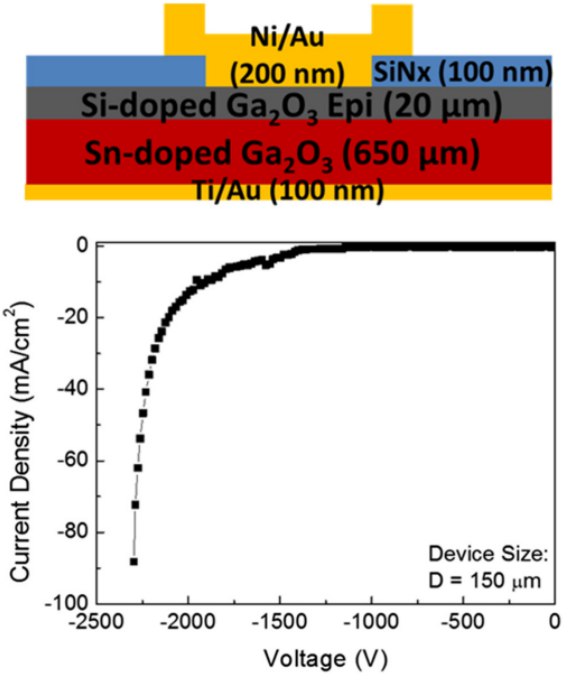

Figure 3.1: Cross sectional view of rectifiers (Top). Reverse biased I-V characterstics (Bottom).

how rectifiers that have been described thus far continue to operate substantially below theoretical limitations. By exhibiting a junction barrier Schottky (JBS) diode design, where the drift layer reduces away from the surface under reverse bias by using a pn junction, even greater breakdown voltage may be achievable. When it comes to Ga_2O_3, pn type heterojunctions have been shown utilizing Ga2O3 deposited on 6H-SiC and Li-doped NiO_2 or Cu_2O. A further possibility might be α-$(Rh, Ga)_2O_3$. For broad bandgap oxides such as Cu_2O, the pn junction's turn-on voltage is higher than that of the Schottky diode. CuO_2 or CuI might be used to create the guard ring for Schottky diodes. Take note that rectifiers that have been described thus far continue to perform substantially below theoretical bounds, as Fig. 2 illustrates.

Voltage and current measurements were performed on Ga_2O_3 films to achieve breakdown. Measurements shows that it produces high(2.47kV) reverse breakdown voltage, and the current value was minimum not depending on the bias polarity. For withstanding high field strengths, there is no need of edge termination. As diameter varies the breakdown voltage also varies as for 20um diameter the breakdown voltage is 1600V and for 0.53mm diameter it's 250V. The impact of crystal defects identified by etch pit delineation says that not all voids cause leakage current and that dislocations are strongly associated with the rectifier's reverse leakage current. Thus sensitivity to defect density is determined by the substrate's orientation.

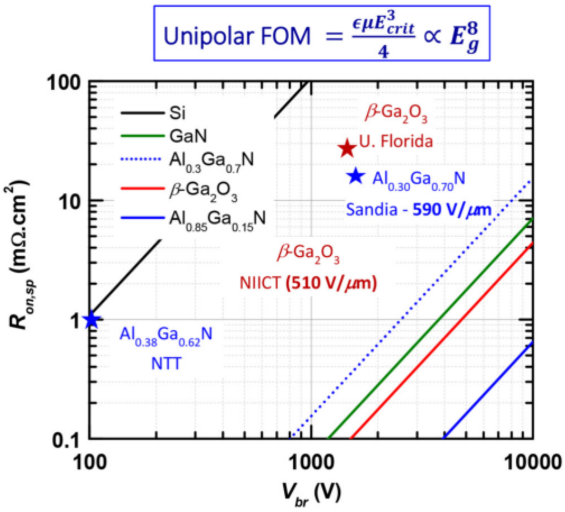

Figure 3.2: On-state resistance plot for vertical rectifiers on Ga_2O_3 and AlGaN

The demonstration of strong forward conduction currents is also crucial. Reports of pulsating electrical currents up to 2 A were made. By delivering a voltage pulse to the Schottky contact and measuring the flow of current via a wideband current probe attached to an oscilloscope, the devices' forward I-V characteristics were determined. Currents in Large area devices were about 2A with a mximum value upto 2.2A. Excess heating up was not a major problem because there were single sweeps, and there was no performance deterioration seen in the devices.

In summary, for rectifiers, it is challenging to obtain a minimal turn-on voltages and high breakdown because Ga_2O_3 lacks p-type doping, which might be a consequence of the band structure. β-Ga_2O_3 based devices have not yet achieved the anticipated breakdown voltage of 8 MV/cm. The breakdown of around 4 MV/cm has been attained by the most effective Schottky diodes based on β-Ga_2O_3. It's important to make sure that the junction's edge termination is done correctly. The breakdown voltage of the devices can be as low as 10%–20% of the ideal value. Moving along the semiconductor suface, decrease in the peak value of electric field and movement in the position of the avalanche breakdown towards the bulk of the device, the different edge termination strategies aim to limit the creation of electron hole avalanches.

3.2 Ga_2O_3 Mosfets

The efficiency of SiC MOSFETs, which may be attributed to its fundamental features such as high critical field, wide bandgap, ambipolar doping and long minority carrier lifetime, has led to the formation of high-voltage power converters. GaN power transistors finds use in the 600 V market sectors such as data center server power supply. GaN heterostructures have been employed in the rf domain for years and are widely used in mobile phone applications. Ga_2O_3 has to have a power output ten times greater than SiC in order to compete with traveling wave tube (TWT) devices considering frequency spectrum at the lower end. If utilized as a beta-voltaic source, an application that has been especially well-suited for single crystal diamond. Ga_2O_3 may be also be able to supply power for space or underwater electronics because of its wide bandgap [3]. Because Ga_2O_3 lacks p-type doping, vertical transistor designs made of commercial native substrates that are affordable and big in area must rely on current channels that are limited by etched fins or implanted current blocking layers. In fact, the most promising designs for the development of Ga_2O_3 devices are the fin-based vertical junction field-effect transistor (JFET) and the Ga2O3 current aperture vertical electron transistor (CAVET), according to recent publications.

Although most of the Ga_2O_3 available are of the depletion type with n-type channels employing SiO_2 as dielectric. Major problem of power MOSFET occurs because of the lower electron mobility at the SiO_2 / 4H-SiC interface.The commercialization of two-terminal devices must be successful in order to support further efforts toward transistor development. In a similar vein, the SiC Schottky diode reached commercialization nearly ten years ahead of the MOSFET.

3.3 Ga_2O_3 FETs and solar-blind photodetectors on exfoliated flakes

Numerous instances of photodetectors, diodes, and mos transistors built on scrubbed Ga_2O_3 flakes or membranes have been published. Figure 3 represents a schematic of the steps involved in making Ga_2O_3 flake devices. The lattice constants of monoclinic β- Ga_2O_3, however, exhibit an enormous anisotropy (a [100] = 12.225 Å and b [010] = 3.039 Å, c [001] = 5.801 Å), which enables it to split into individual free-standing flakes and is referred to as a nano-layer.

Exfoliated β- Ga_2O_3 flakes have been used in the demonstration of a number of electronic devices, such as junction FET, p-n diode, MOSFET, Schottky diode, and metal insulator field effect transistor (MISFET). In order to construct p-n junctions, heterostructures are required since p-type β- Ga_2O_3 is currently unavailable.

In conclusion, β- Ga_2O_3's broad bandgap makes it perfect for solar-blind photodetectors. Thus,

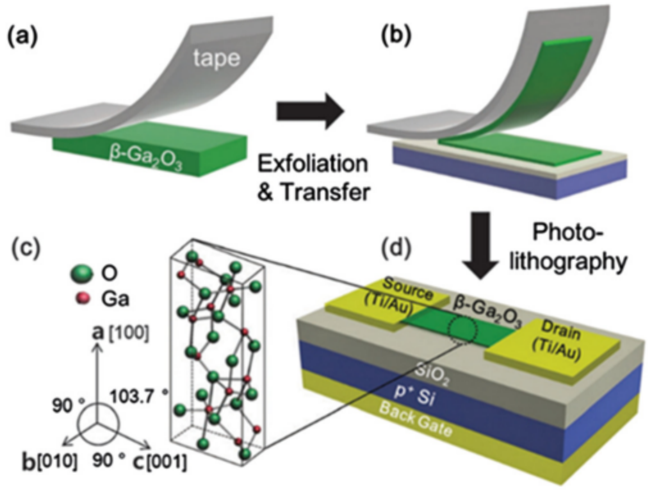

Figure 3.3: Step by process of mechanical exfoliation of β- Ga_2O_3 flakes and fabrication of device with the help of exfoliated flake

exfoliated β- Ga_2O_3 flakes have been reported to be used in various nanoscale optoelectronic equipment to detect UV-C wavelengths, such as Schottky-barrier photodiode, photoconductive detector and metal photodetector. These devices have demonstrated quick switching, strong responsivity, and a good rejection ratio of UV-C/UV-A for photo-response properties. Graphene, being a conductive electrode that is UV-transparent, was particularly useful in improving the photoresponse properties when combined with the exfoliated β- Ga_2O_3 nano-layer. Moreover, new functional devices may be made possible by the heterostructures that are of the eliminated β- Ga_2O_3 nano-layer and other 2D materials. β- Ga_2O_3 is of a great potential material for a solar-blind photodetector, but it still has to be addressed because of continuous photoconductivity and defect-induced non-idealities that are typical of oxide and III-nitrides.

Chapter 4

Future Needs

Wide bandgap power electronics find commercial use in electric cars for power flow management and recharging systems, wireless charging, and more energy-efficient motor drives. Eighteen years ago saw the introduction of the first commercially accessible SiC diode, which has gradually displaced Si diodes in certain applications. SiC MOSFETs, which offer better device efficiency and dependability, are also offered for sale. Full-SiC power modules are now possible because to the availability of SiC transistors, which offers advantages over Si-based power modules. In contrast to SiC devices, GaN power devices are less developed. Low voltage high frequency applications like wireless power and Lidar, where GaN offers a unique selling proposition, as well as the consumer power supply sector, where size and weight are crucial, are what drives the industry.

For Ga_2O_3 to be useful, military funds must be provided for its further development in order to use it in high-voltage, low-frequency applications that are beyond the scope of GaN and SiC. It could offer increased effectiveness in the crucial AC-to-DC conversion sector. Given the immaturity of the technology, it is unlikely that Ga2O3 will completely replace all other pertinent materials in the full spectrum of power and power conversion applications, including motor drives, electric and hybrid cars, power supplies for computers, data centers, telecoms and wireless power transfer. The following areas need constant development in order to find a use in the power switching and conversion application space:

1. **Epitaxial growth** - Controlled manner growth of high quality epitaxial structures on Ga_2O_3 Substrates could be an easy task. Defects in the materials leads to collapse in the current value for Ga_2O_3 because there is no negligibility in the density of traps.

2. **Improved Ohmic Contacts** - The development of selective ion implantation doping and the use of interfacial engineering and inter-layers, including conducting oxides of aluminum zinc oxide ITO, and similar materials, to minimize individual contact resistance.

3. **Thermally stable schottky contacts** - These might include carbides ,borides and tungsten that have limited reactivity with Ga2O3 and high melting temperatures. These devices surpass the theoretical limitations of unipolar devices by maintaining the high voltage blocking capability while decreasing on-state resistance.

4. **Enhancement-mode operation** - Ga_2O_3's lack of p-doping may be somewhat mitigated by integration with p-type oxides as CuI, Cu_2O, or NiO. Although far from optimal, GaN-on-Si e-mode devices for 200 V and 650 V applications have come to rely more and more on a p-GaN cap for channel depletion.

5. **Reduction of dynamic** R_{ON} - Both MOSFETs and rectifiers, for example, should have minimum voltage across the two terminals when they are forward biased and low leakage current when they are reverse biased . Schottky diodes are known for their fast switching speeds, however their off-state leakage is frequently substantial. The breakdown voltage is proportional to the on-resistance. Higher Ron decreases switching speed and increases conduction loss.

Chapter 5

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 and SiC are now the same. 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, Ga2O3 may assist these materials rather than replace them. However, SiC is still only employed in tiny quantities, necessitating the employment of silicon IGBTs as a backup.

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