GaN MOSFETs

- The Materials
- The MOSFET
- The GaN MOSFET

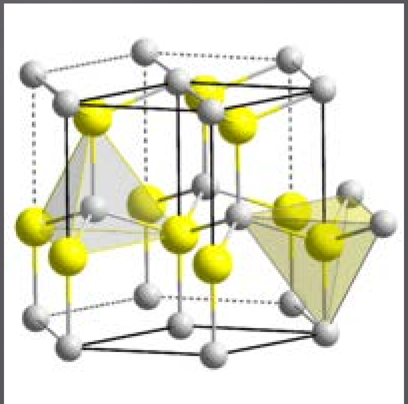
Gallium Nitride

Chemical Reactions:

$$2\,Ga + 2\,NH_3 \rightarrow 2\,GaN + 3\,H_2$$

$$Ga_2O_3 + 2\,NH_3 \rightarrow 2\,GaN + 3\,H_2O$$

- Crystal Can be grown usually on substrates through means of: Molecular-Beam Epitaxy (MBE), Metal Organic Chemical Vapor Deposition(MOCVD), or more recently entire crystals using Autoclaves



Gallium Nitride Properties

Molar mass	83.73 g/mol
Appearance	yellow powder
Density	6.15 g/cm^3
Melting point	>2500°C[1]
Solubility in water	Reacts
Refractive index (nD)	2.429

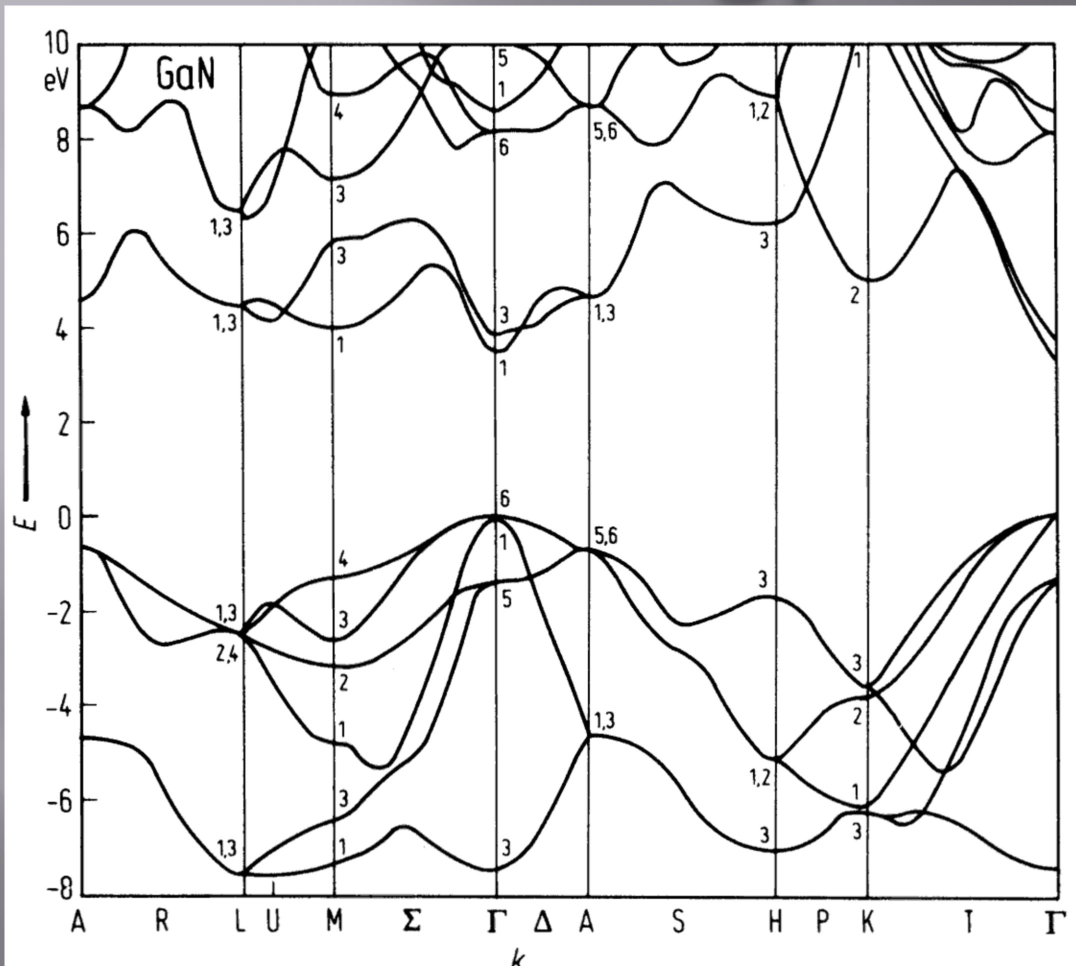
http://en.wikipedia.org/wiki/Gallium_nitride

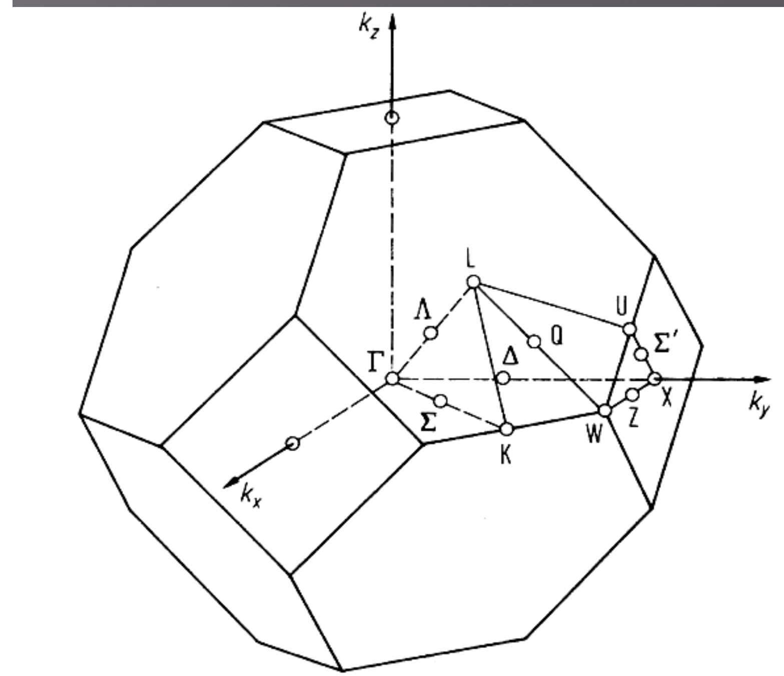
Gallium Nitride

This is a gallium nitride crystal that was grown using an autoclave, by a group called Ammono.

http://spectrum.ieee.org/semiconductors/materials/the-worlds-best-gallium-nitride/1

GaN Energy Band Diagram





http://www.ioffe.ru/SVA/NSM/Semicond/GaN/figs/fmd28_1.gif

Material Properties

	Si	GaAs	InP	GaN	4H-siC
Bandgap *(eV)*	1.1	1.43	1.35	3.4	3.26
Breakdown Field *(V/μm)*	30	40	50	300	200<300
Electron Mobility *(cm^2/Vs)*	1500	8500	5400	1500 (2DEG)	700
Saturated Electron Velocity *(10^7 cm/s)*	1	<1.0	1	1.3	2
Peak Electron Velocity *(10^7 cm/s)*	1	2.1	2.3	2.5	2
Thermal Conductivity *(W/cmK)*	1.3	0.55	0.68	>1.5	<3.8
Lattice Constant (a) *(A)*	5.43	5.65	5.87	3.19	3.07
Dielectric Constant *(ε_r)*	11.7	12.9	12.5	9	9.7

http://www.gainmicrowave.com/public/gallium_nitride_overview.php

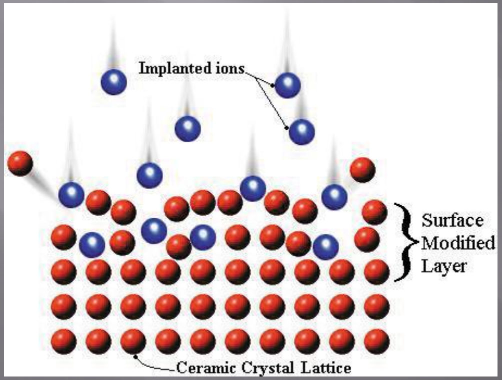
Material Properties

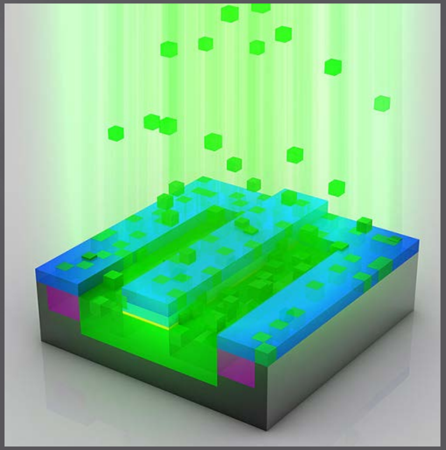
Properties	Si	GaAs	4H-SiC	GaN
Bandgap (eV)	1.11	1.43	3.26	3.42
Relative Dielectric Constant	11.8	12.8	9.7	9.0
Breakdown Field (V/cm)	2.5e5	3.5e5	35e5	35e5
Saturated Velocity (cm/sec)	1.0e7	1.0e7	2.0e7	1.5e7
Electron Mobility (cm^2/V-sec)	1350	6000	800	1000
Hole Mobility (cm^2/V-sec)	450	330	120	300
Thermal Conductivity (W/cm-°K)	1.5	0.46	4.9	1.7

http://www.aethercomm.com/articles/9.pdf

Gallium Nitride

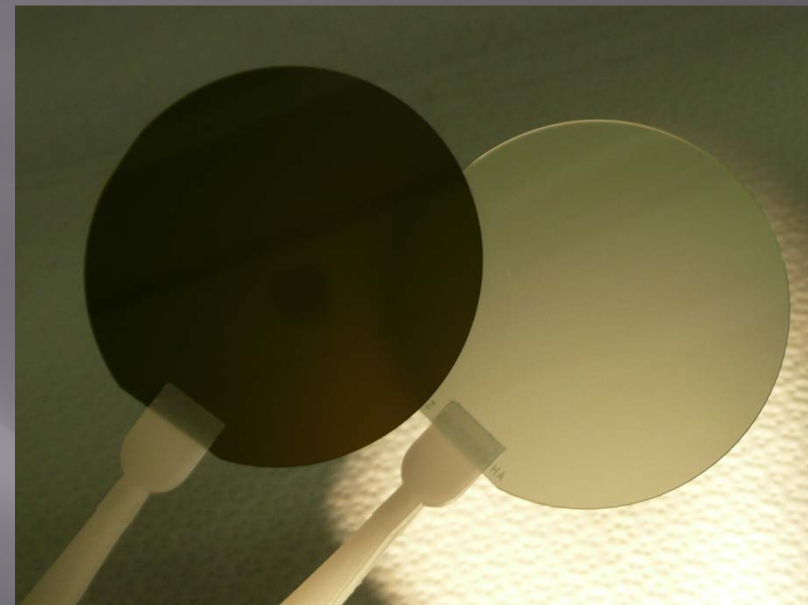
- Can be doped to be N-type with either silicon or oxygen.
- Can also be doped to P-type with magnesium.
- Doping of Gallium Nitride has been preformed using ion implantation





Substrate Materials

Sappire Wafer

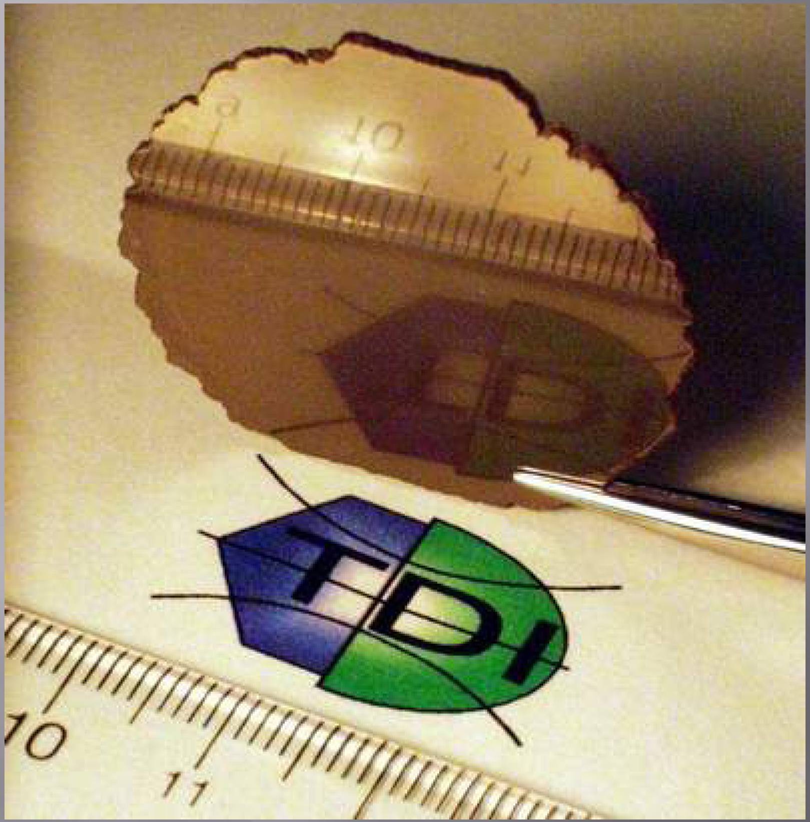


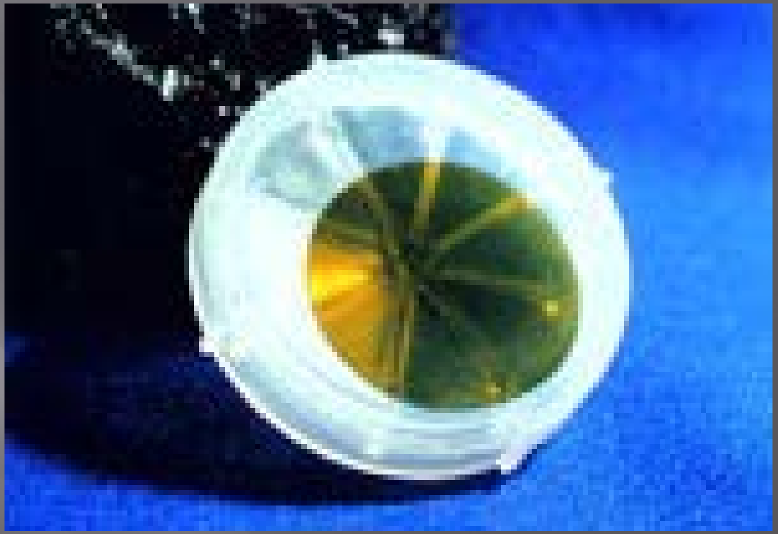
Silicon Carbide

http://www.zenithtech.com.tw/zen/products_more.asp?pid=714

http://www.seikoh-giken.co.jp/en/business/sic.html

Substrate Materials





Gallium Nitride

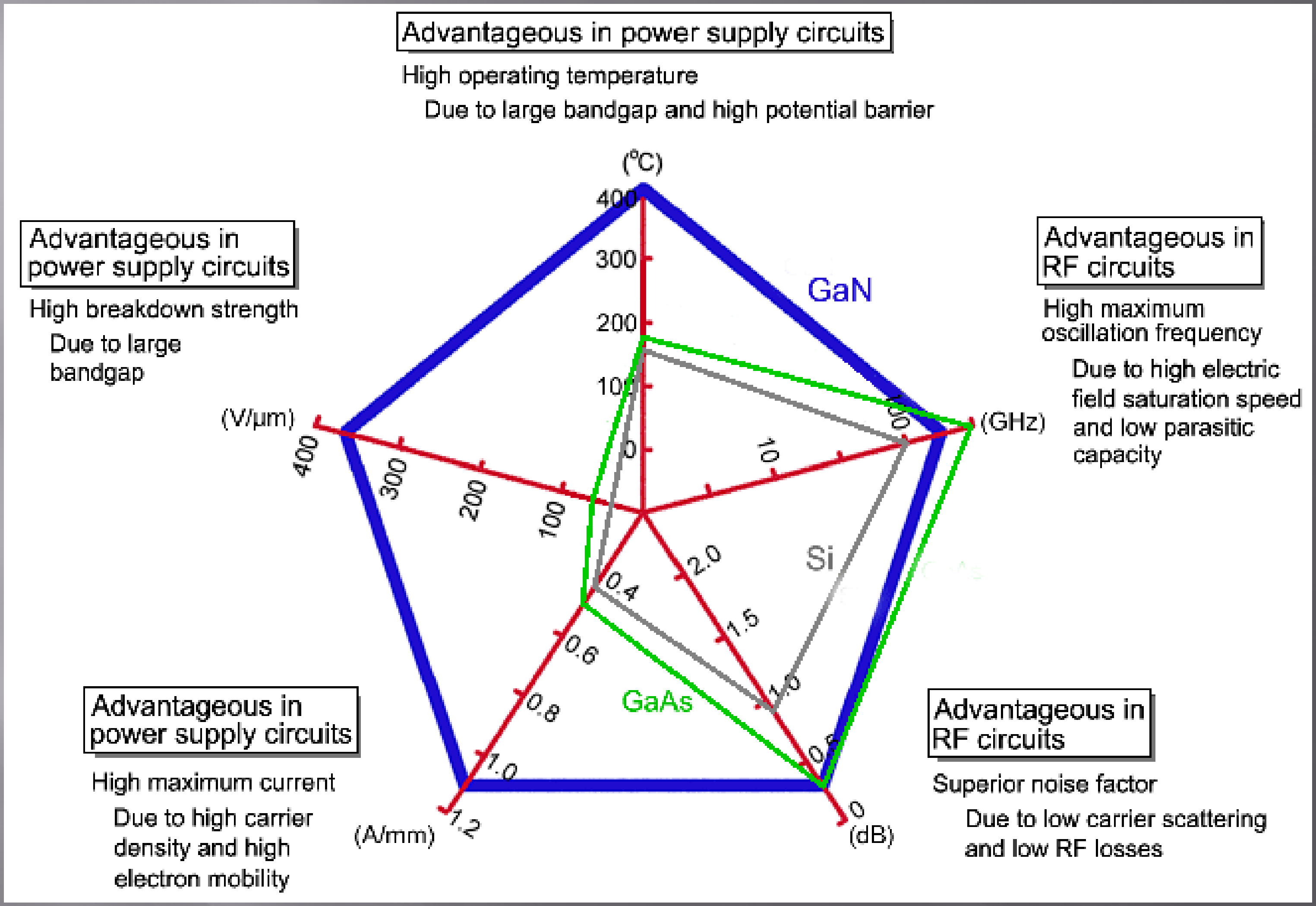
http://www.semiconductor-technology.com/projects/epitaxial_wafer_fab/epitaxial_wafer_fab4.html

Mechanical and Electrical Properties

Materials Property	Si	SiC-4H	GaN
Band Gap (eV)	1.1	3.2	3.4
Critical Field 10^6 V/cm	.3	3	3.5
Electron Mobility (cm^2/V-sec)	1450	900	2000
Electron Saturation Velocity (10^6 cm/sec)	10	22	25
Thermal Conductivity (Watts/cm^2 K)	1.5	5	1.3

Substrate	GaN	Si <111>	Sapphire (Crystal of Al2O3)	SiC 6H	Ge <111>
Lattice Constant (Å)	3.19	3.84	2.75	3.08	4.0
Coefficient of Thermal Expansion (CTE)	5.6	2.6	7.5	4.2	5.9

http://www.digikey.com/Web%20Export/Supplier%20Content/Microsemi_278/PDF/Microsemi_GalliumNitride_VS_SiliconCarbide.pdf?redirected=1



http://www.gansystems.com/technology/why-gallium-nitride

MOSFETs

- Silicon is has been used executively for these devices.
- Fabrication method can be used?
- Performance of the FETs under the various electrical and thermal conditions?
- What are the weaknesses of these devices and where is the current ceiling?
- Are these devices RF operation capable?

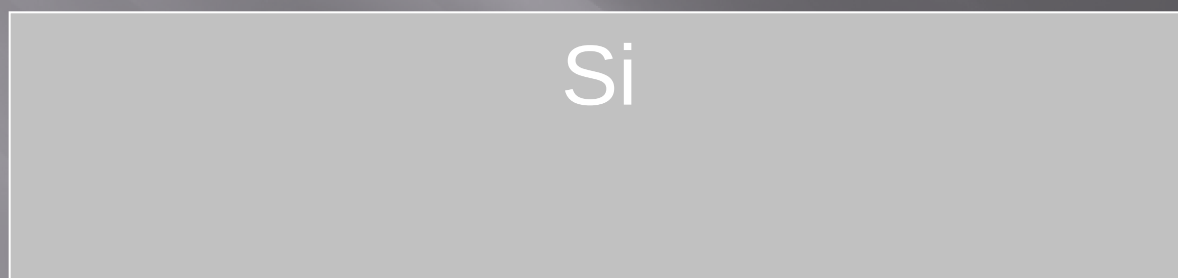
MOSFET Limitations

- Primary material that is used is Silicon due to its ease to grow oxide.
- MOSFETs by the thickness of the oxide, which effects the trans-conductance
- The parasitic capacitance also cause the device to have un-wanted frequency reponses

MOSFET Limitations

- Silicon has limited electrical and thermal properties that will only allow a certain performance
- Even though there are other issues with the Si MOSFET there is a theoretical limit, based on Si material properties

MOSFET FAB



MOSFET FAB

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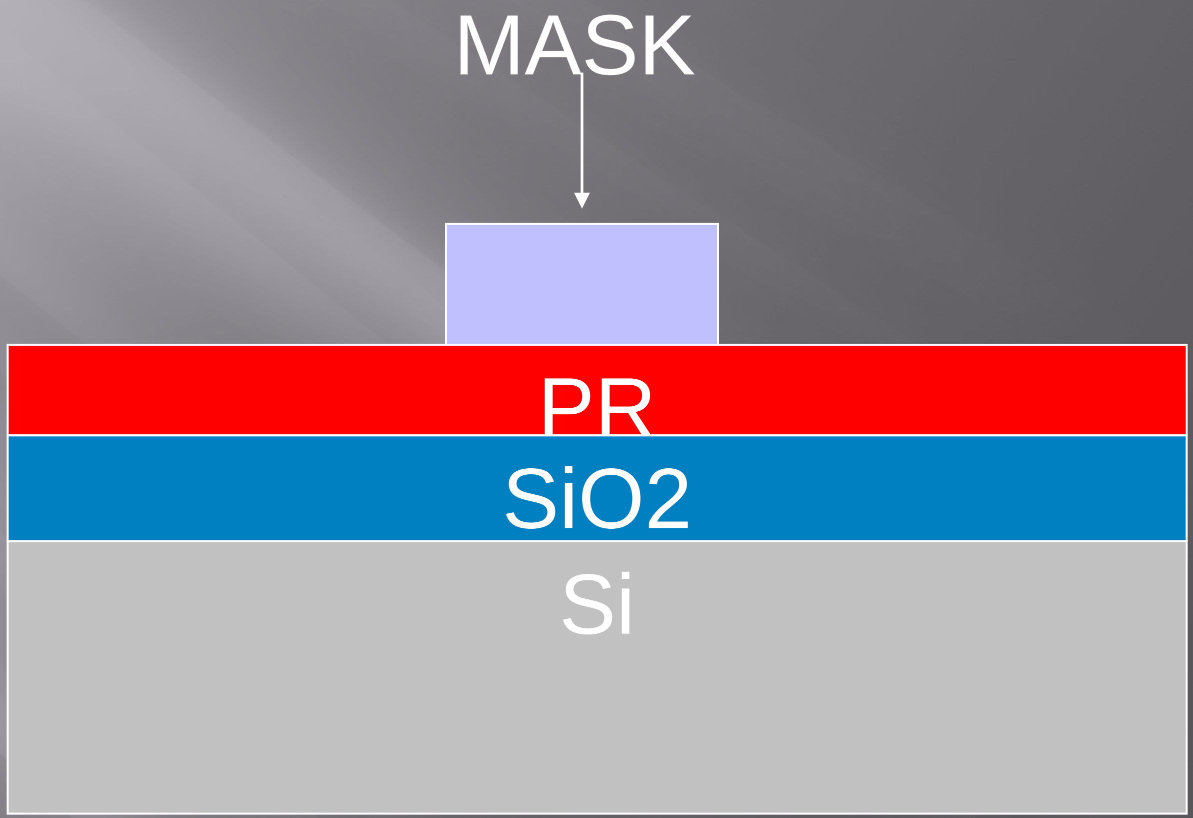

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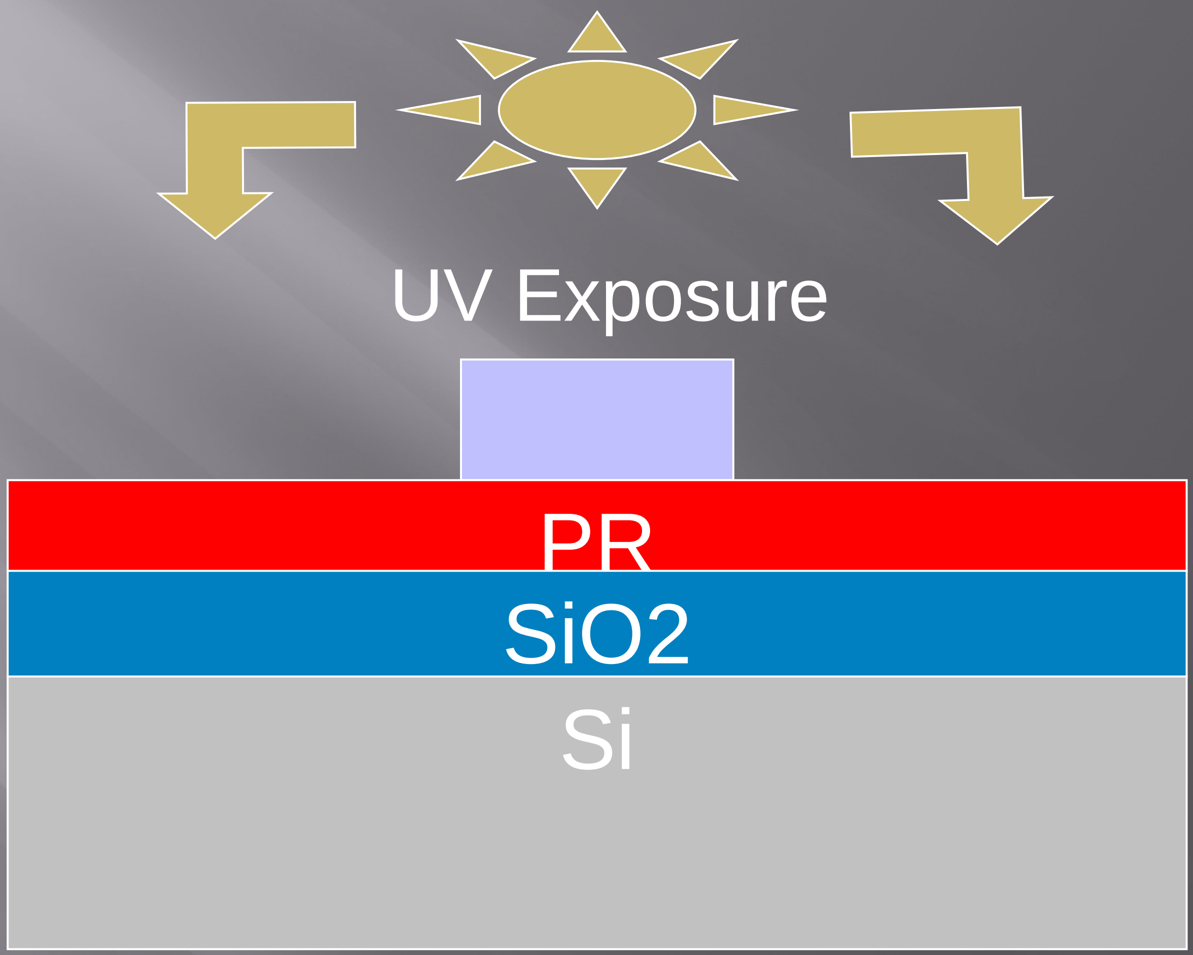

MOSFET FAB

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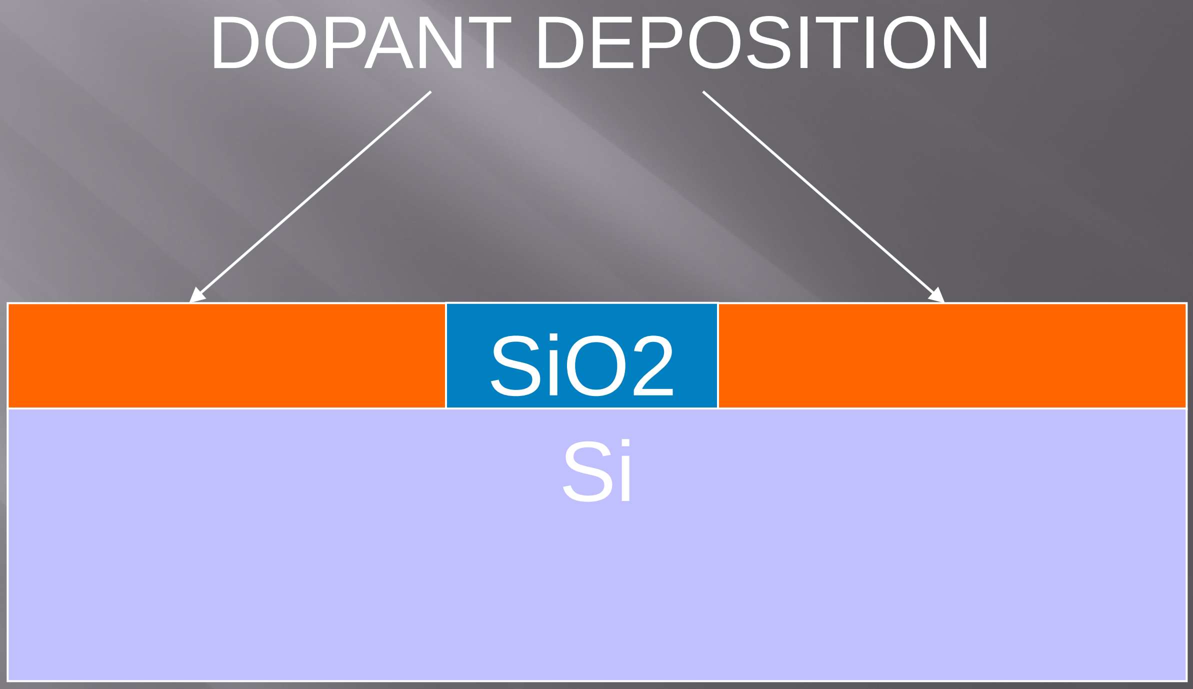
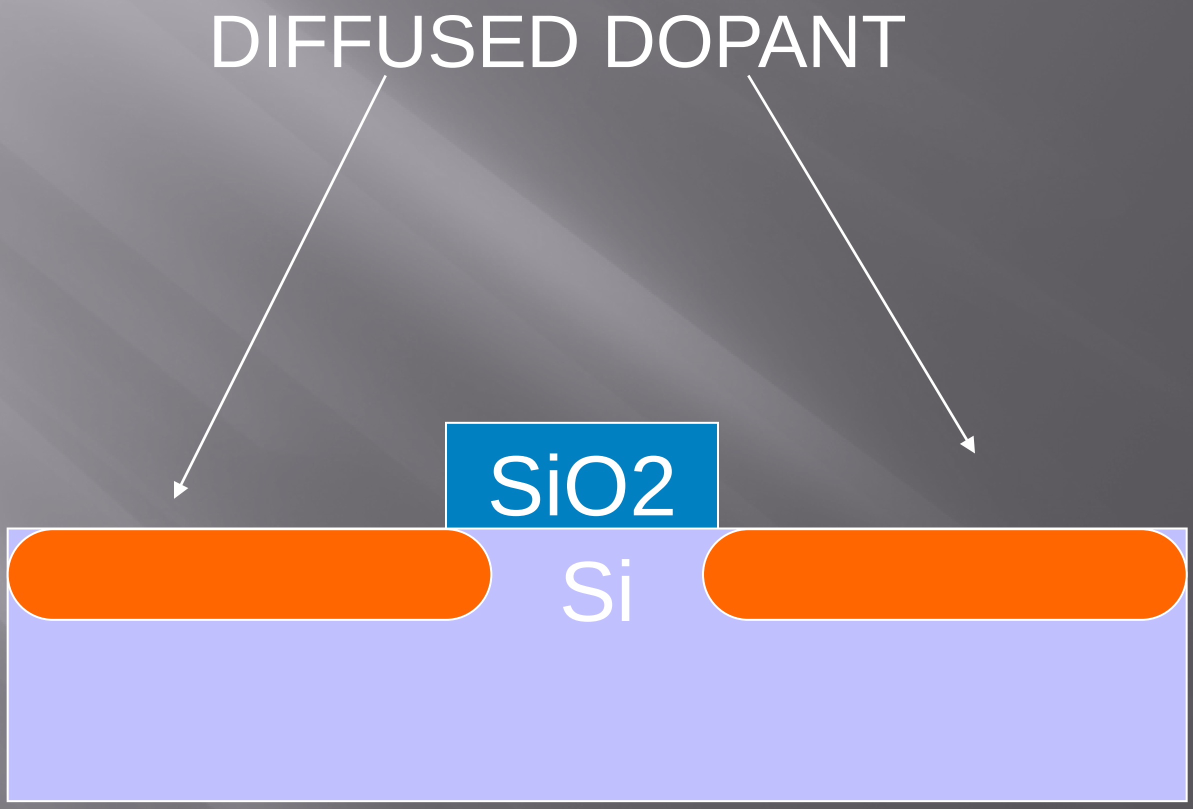
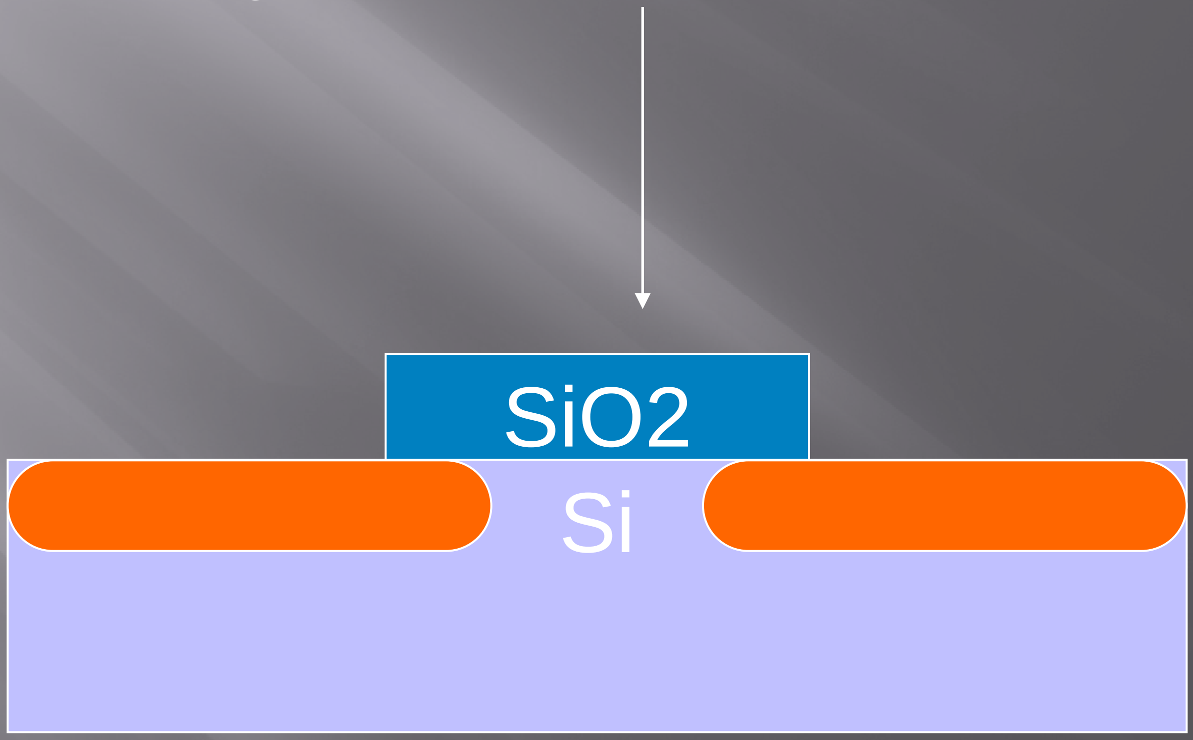


MOSFET FAB

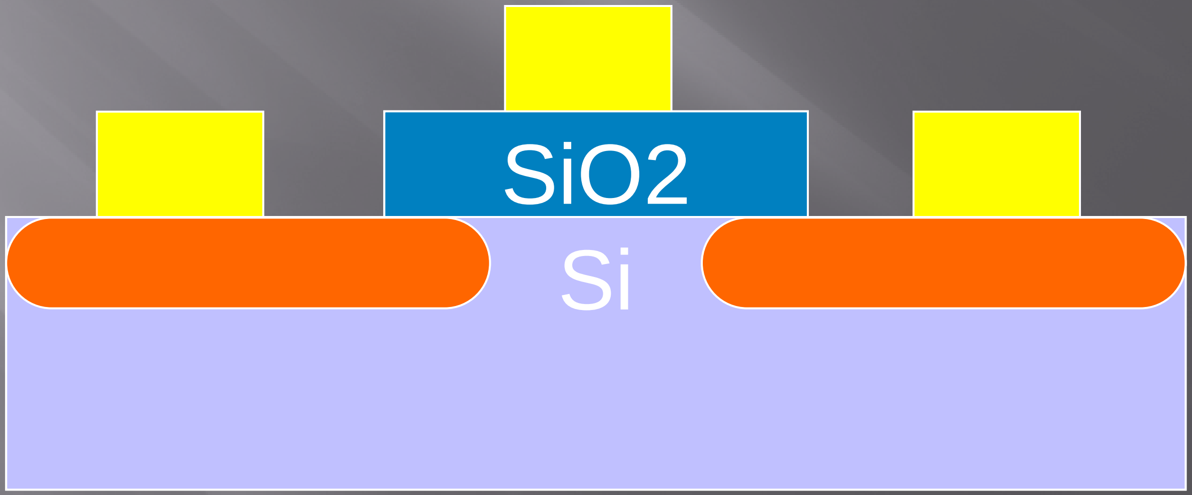


MOSFET FAB

HIGH QUALITY OXIDE FOR THE GATE



MOSFET FAB



GaN MOSFETs

- Fabrication Differences
- Challenges with Materials Compatiblity
- ---Lattice Structure Differences (Shown images of lattice structure)
- Brief Advantages to the GaN material

GaN MOSFET APPLICATIONS

- The areas of interest are for RF power amplifiers and for high power switching
- The RF power amplifier for RADAR application where reliability and low noise are primary concerns
- For high power switching used to in the control circuitry for hybrid automobiles.

GaN MOSFET APPLICATIONS

- An advantage as a RF power amplifier is having a device that is normally off.
- The biasing of RF amplifiers is challenging because most current amplifiers are normally on, which if not handled properly can cause damage.
- Another advantage is the gate current does not flow into the channel of the device preventing, un-wanted signal which may cause ringing

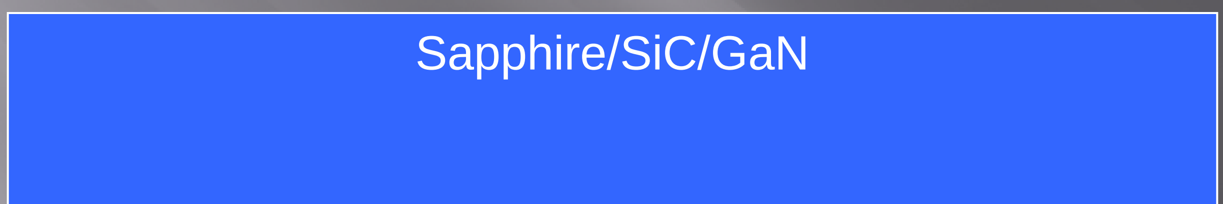
GaN MOSFET APPLICATIONS

- For high power switch the GaN MOSFET have a high thermal conductivity to vehicle the removal of heat.
- The GaN transistors are capable of operating at higher temperatures than Si base.
- The higher mobility is the properties that the high current flow without as much energy lost, as with silicon.

GaN MOSFETs

- The main challenge with GaN MOSFETs the growth of a quality oxide
- There are issues with lattice matching and impurities that cause dips in the energy band and disruptions in current flow

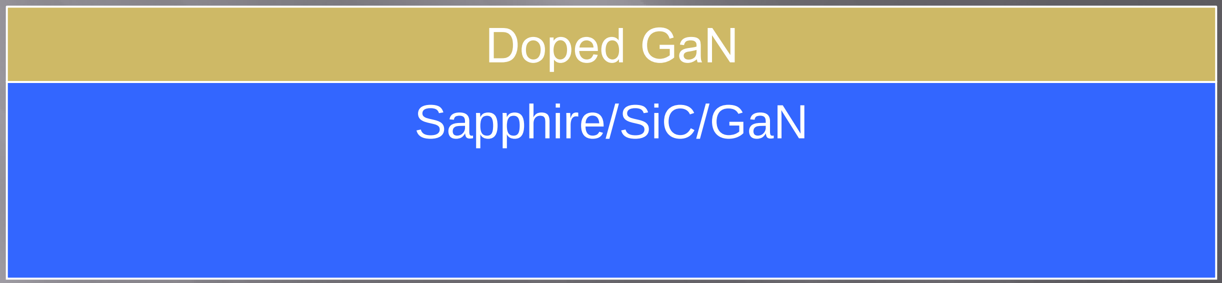
Fabrication of GaN MOSFET



http://iopscience.iop.org/0268-1242/25/12/125006/pdf/0268-1242_25_12_125006.pdf

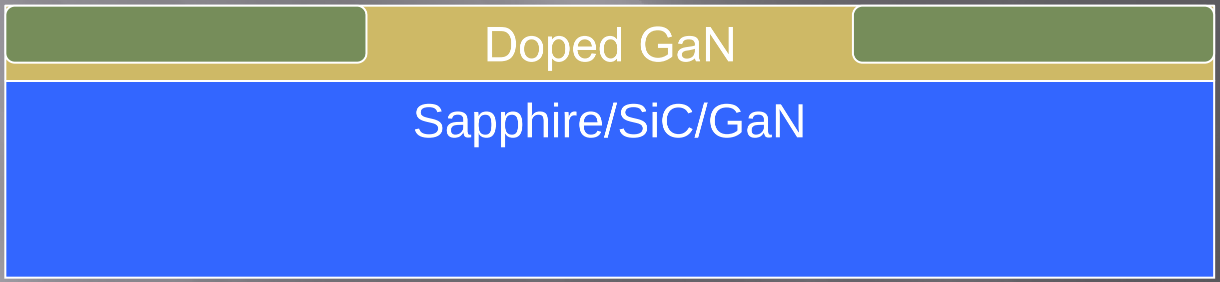
Fabrication of GaN MOSFET

Doped GaN is grown in a substrate, using MOCVD, or MBE to a thickness around 1um



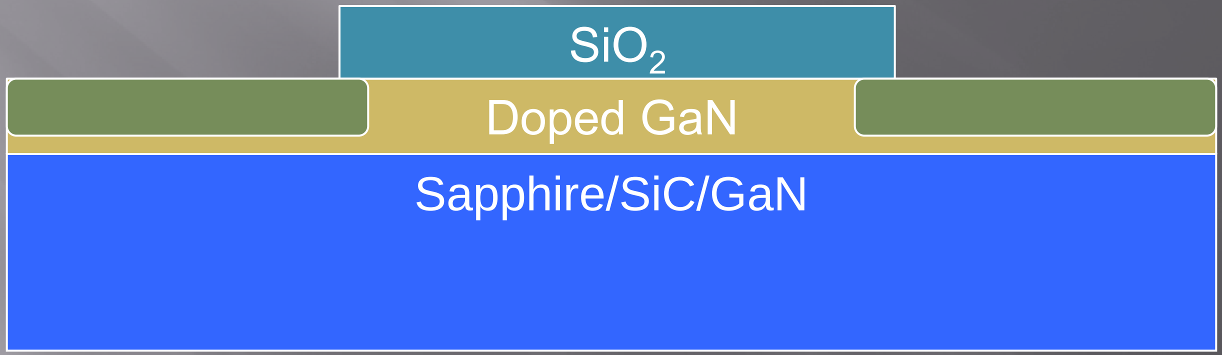
Fabrication of GaN MOSFET

Silicon ions are implanted and then diffused in the GaN layer to make the source and the drain at a depth fo 150 nm



Fabrication of GaN MOSFET

SiO_2 is deposited on the surface of the GaN with a thickness of about 60 nm

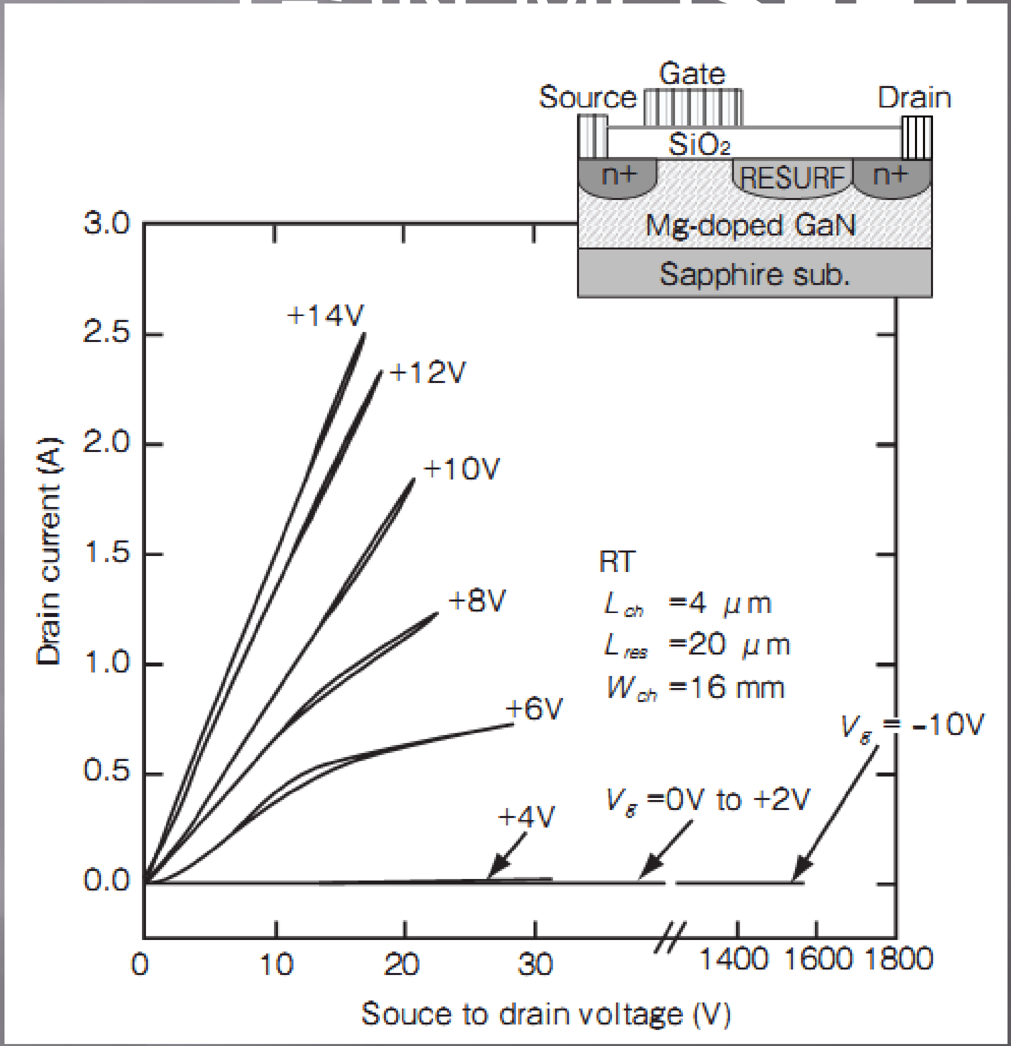


Fabrication of GaN MOSFET

Ti/Al metal is deposited using a sputtering system.

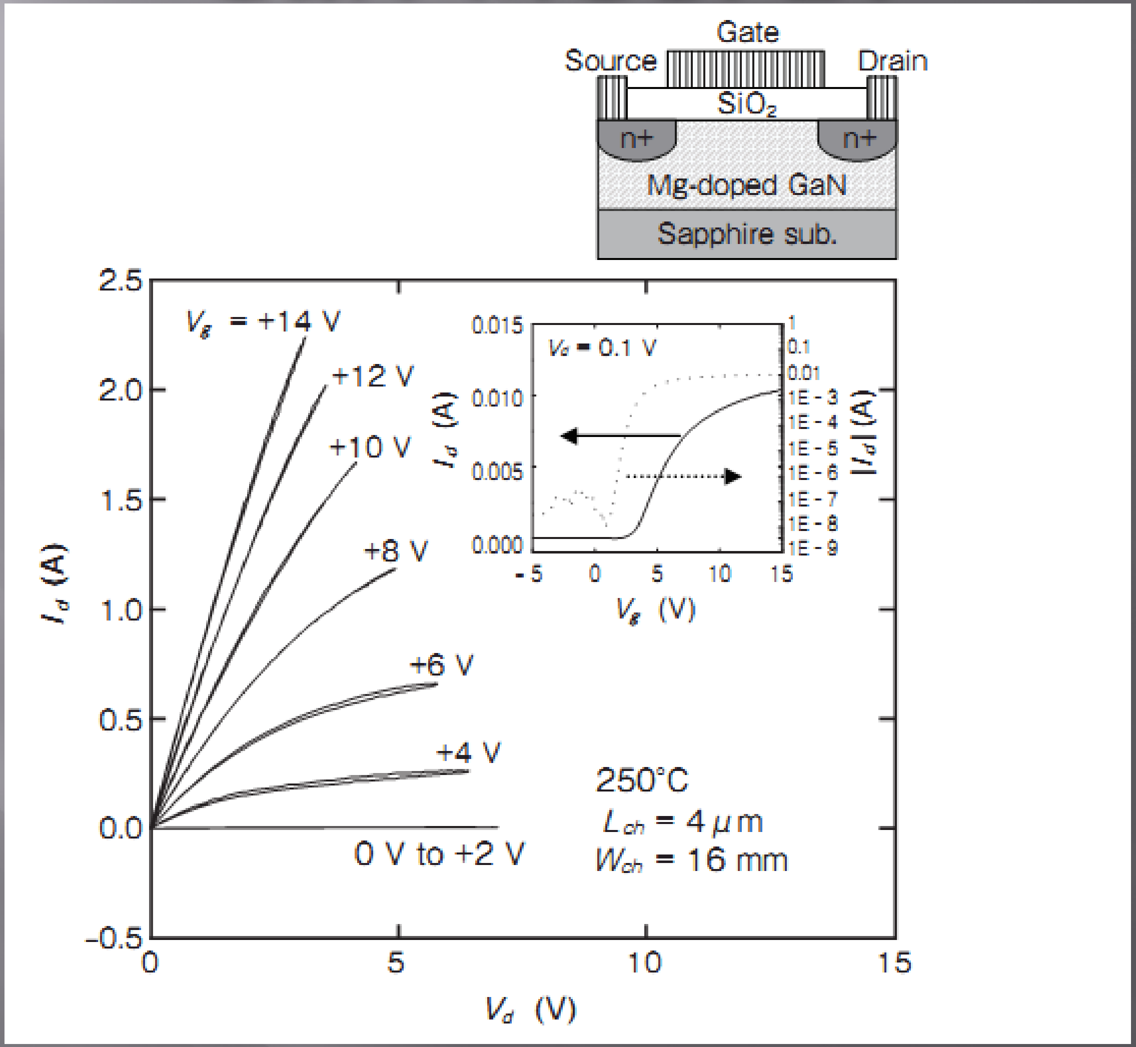
GaN MOSFET

Operation at 250℃



Y. Niiyama, T. Shinagawa, S. Ootomo, H. Kambayashi, T. Nomura, and S. Yoshida: "High-quality SiO2/GaN interface for enhanced operation field-effect transistor," Semiconductor Science and Technology, Volume 25, Issue 12, pp. 125006 (2010).

GaN MOSFET



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