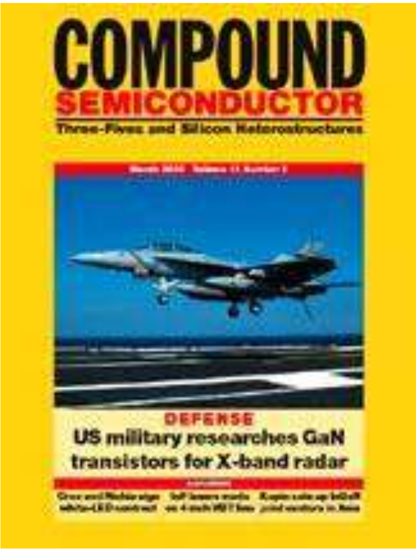
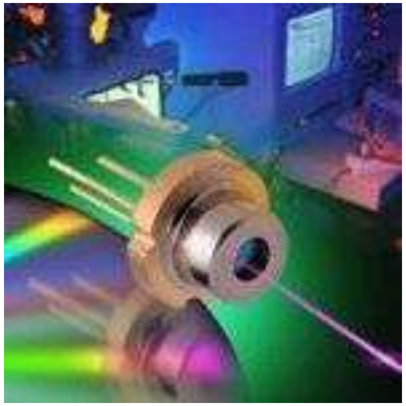
Gallium Arsenide Semiconductors





Overview

- Compound Semiconductor Materials
- Interest in GaAs
- Physical Properties
- Processing Methods
- Applications

What is Gallium Arsenide?

Gallium Arsenide (GaAs) is a compound semiconductor: a mixture of two elements, Gallium (Ga) and Arsenic (As). Gallium is a byproduct of the smelting of other metals, notably aluminum and zinc, and it is rarer than gold. Arsenic is not rare, but is poisonous.

The uses of GaAs are varied and include being used in some diodes, field-effect transistors (FETs), and integrated circuits (ICs). GaAs components are useful in at ultra-high radio frequencies and in fast electronic switching applications. The benefit of using GaAs in devices is that it generates less noise than most other types of semiconductor components and, as a result, is useful in weak-signal amplification applications.

Disadvantages

Advantages and Disadvantages of GaAS

Advantages

- Very high electron mobility
- High thermal stability
- Low noise
- Wide temperature operating range

Disadvantages

- No natural oxide as in Silicon
- High production costs
- Small size (4") ingots

Unlike silicon cells, Gallium Arsenide cells are relatively insensitive to heat. Alloys made from GaAs using Al, P, SB, or In have characteristics complementary to those of GaAs, allowing great flexibility.

GaAs is very resistant to radiation damage. This, along with its high efficiency, makes GaAs very desirable for space applications. However, GaAs does nave drawbacks; the greatest barrier is the high cost of a single-crystal GaAs substrate.

GaAs and Other Compound Semiconducors

Semiconductor (commonly used compounds)		Silicon	Gallium arsenide (AlGaAs/ InGaAs)	Indium phosphide (InAlAs/ InGaAs)[a]	Silicon carbide	Gallium nitride (AlGaN/ GaN)
Characteristic	Unit					
Bandgap	eV	1.1	1.42	1.35	3.26	3.49
Electron mobility at 300 K	cm2/Vs	1500	8500	5400	700	1000-2000
Saturated (peak) electron velocity	$X10^7$ cm/s	1.0 (1.0)	1.3 (2.1)	1.0 (2.3)	2.0 (2.0)	1.3 (2.1)
Critical breakdown field	MV/cm	0.3	0.4	0.5	3.0	3.0
Thermal conductivity	W/cm•K	1.5	0.5	0.7	4.5	>1.5
Relative dielectric constant	ε_r	11.8	12.8	12.5	10.0	9.0

[a] The compounds are loosely known as indium-based.

The higher electron mobility for GaAs shows promise for high speed devices and circuits. The direct gap allows for emission of photons in LEDs and LASER devices.

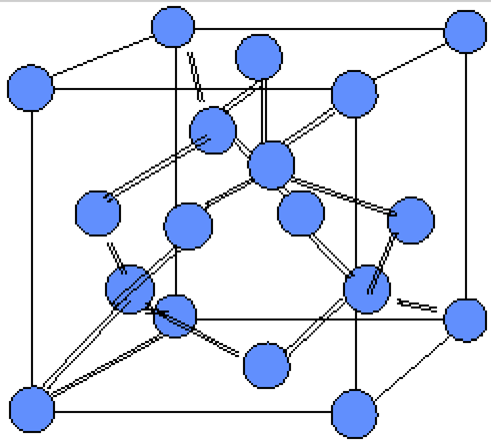
	Silicon	GaAs
Minority Carrier Lifetime	0.003	1E-8
Electron Mobility	1500	8000
Hole Mobility (cm2/Vs)	600	400
Energy Gap (eV)	1.12 (indirect)	1.43 (direct)
Vapor Pressure	1E-8@930C	1@1050C

$$\lambda = hc/E = (6.625E\text{-}34 * 3E8)/(1.6E\text{-}19 * 1.43)$$

$$= 869 \text{ nm} \quad \text{(infrared)}$$

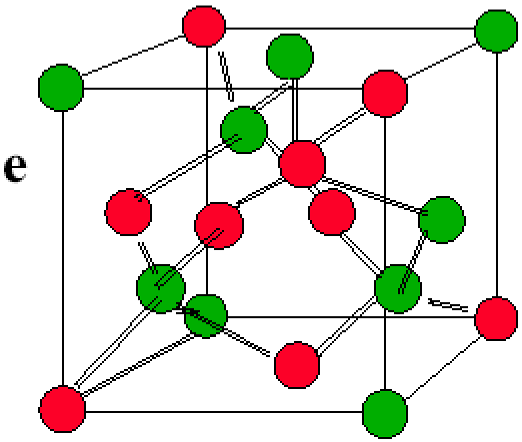
Crystal Structure

Diamond Lattice (Silicon)



Si

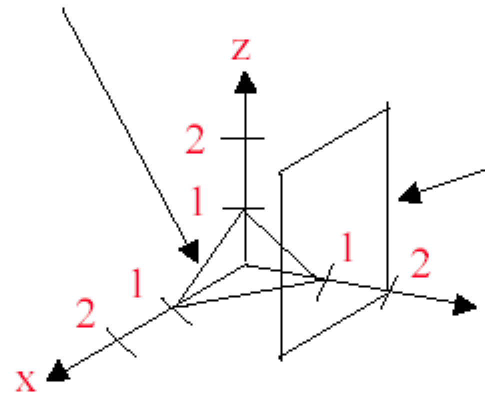
Zincblende Lattice (GaAs)



As
Ga

(111) plane

(100) plane



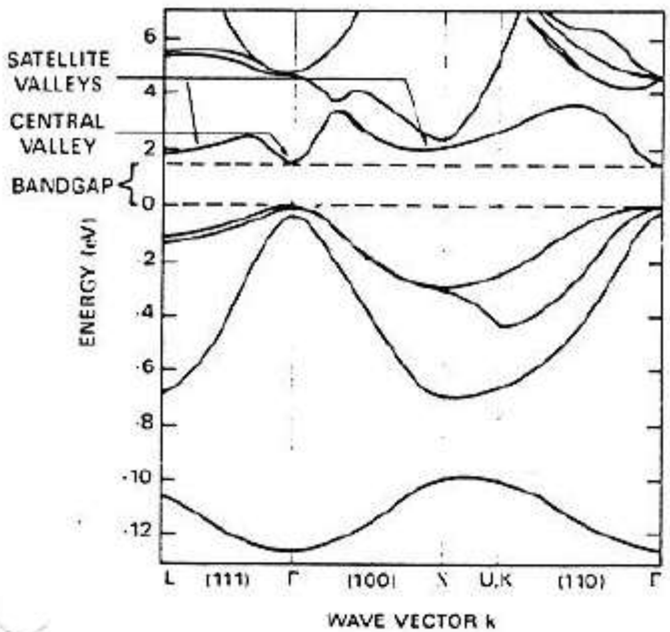
Miller Indices
(1/x,1,y,1/z)
smallest integer set

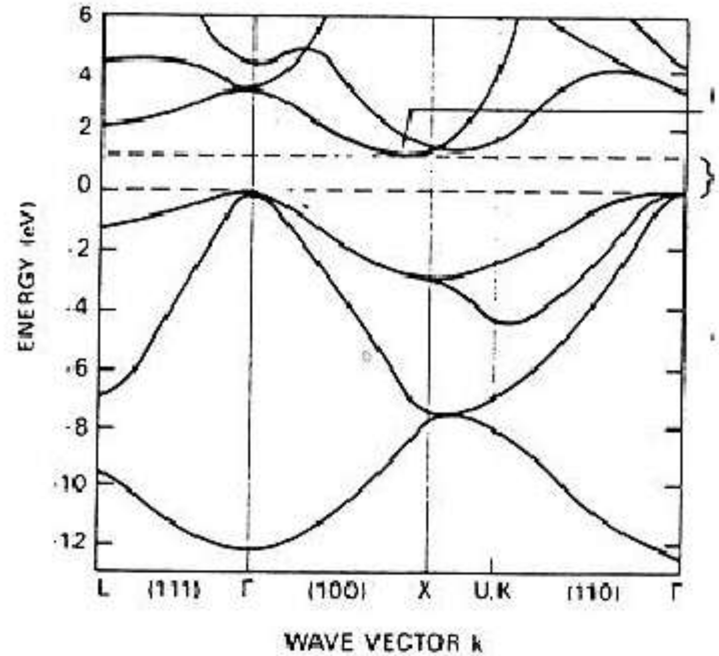
Impurities in GaAs

Impurity	Type	Ionization Energy From Ec	From Ev
S	n	0.0061	
Se	n	0.0059	
Te	n	0.0058	
Sn	n	0.0060	
C	n/p	0.0060	0.026
Ge	n/p	0.0061	0.040
Si	n/p	0.0058	0.035
Cd	p		0.035
Zn	p		0.031
Be	p		0.028
Mg	p		0.028
Li	p		0.023

NOTE: Cr acts as a deep electron trap that can make GaAs appear to be undoped as it traps free electrons from silicon donor atoms that come from the quartz used in the crystal growth process.

Energy Band Structure





Gallium Arsenide

Direct gap semiconductor

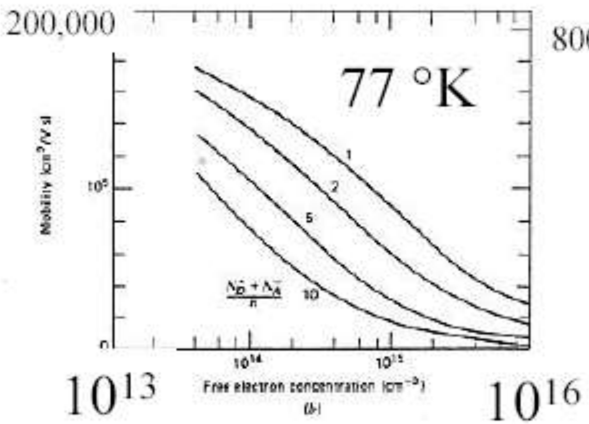
Energy gap = 1.43 eV

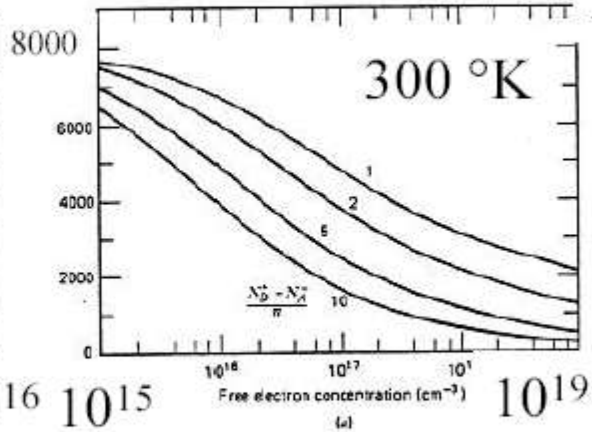
Silicon

Indirect gap semiconductor

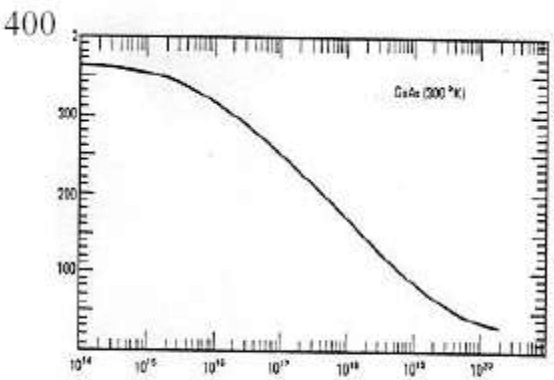
Energy gap = 1.12 eV

Electron and Hole Mobility

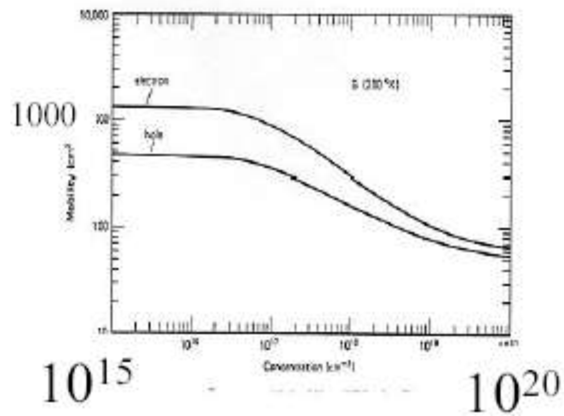




Electron Mobility at 77K and 300K

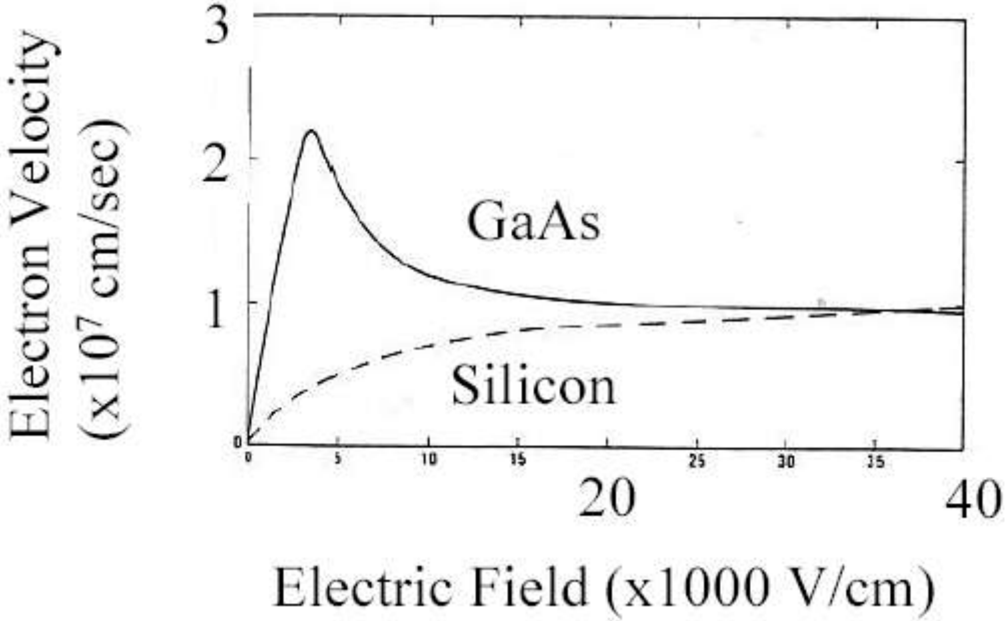


Hole Concentration



Hole Mobility at 77K and 300K

Electron Drift Velocity



Note that drift velocity slows in fields exceeding ~ 1000 V/cm

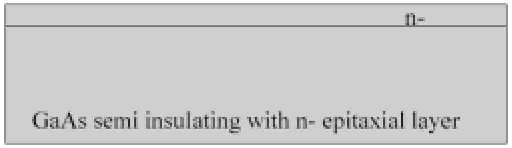
CRYSTAL GROWTH and OXIDES OF GaAs

The vapor pressure of As in GaAs is very low. A GaAs substrate hated to about 500 C begins to lose As from the surface. The wafer can be capped with SiO2 or Si3N4 or the heat treating can be carried out in an Arsenic overpressure. GaAs crystals are often grown in the horizongal Bridgeman technique and the wafers are “D” shaped. Czochralski GaAS wafers are also available up to ~4” in diameter. GaAs wafes are more brittle than Si wafers. 4” GaAs wafers cost about $300 each.

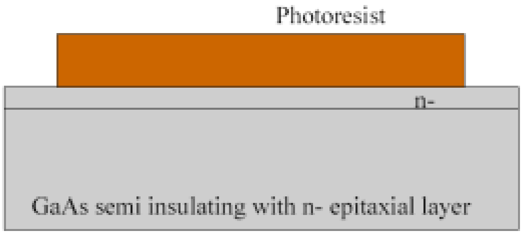
GaAs does not grow a native oxide that is equivalent to SiO2. Ga2O3 and As2O3 and As2O5 oxides that grow on GaAs present more problems than uses

GaAs Processing

Semi insulating starting wafer
5 Levels Photo
2 Levels Ion Implant
2 Levels LPCVD SiO2

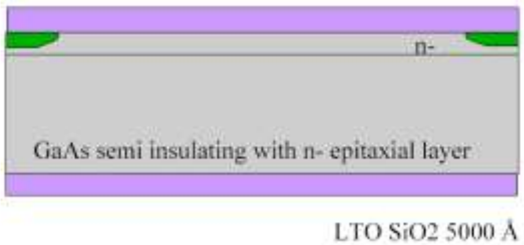


Starting wafer



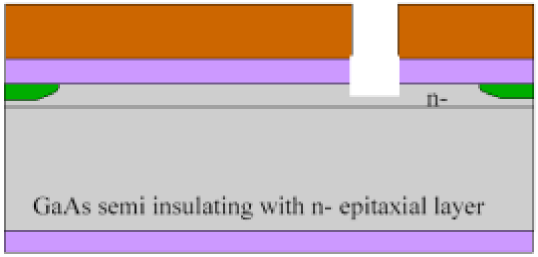
First Photoresist for Channel Stop

Alignment & Channel Stop Implant

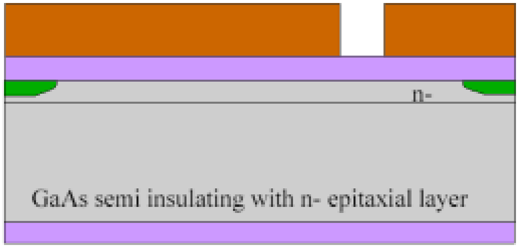


First Encapsulation

2nd Photo Channel Etch

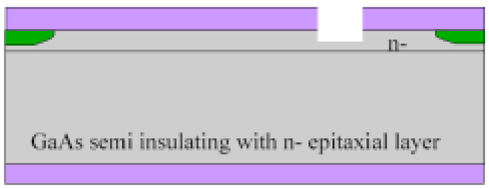


2nd Photo Channel Etch

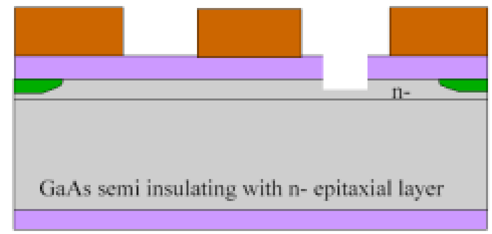


GaAs Processing

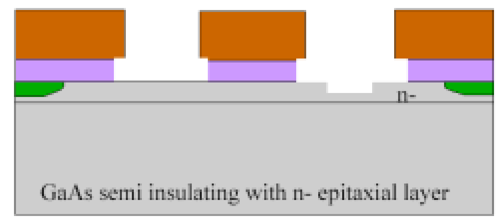
Strip Resist



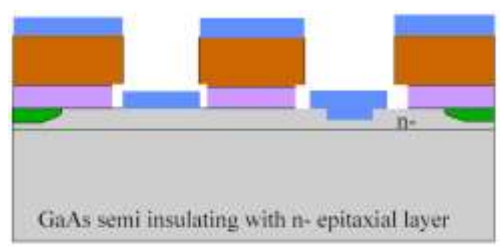
3rd Photoresist Layer for Gates



Etch for Gates



Evaporate Metal for Gates

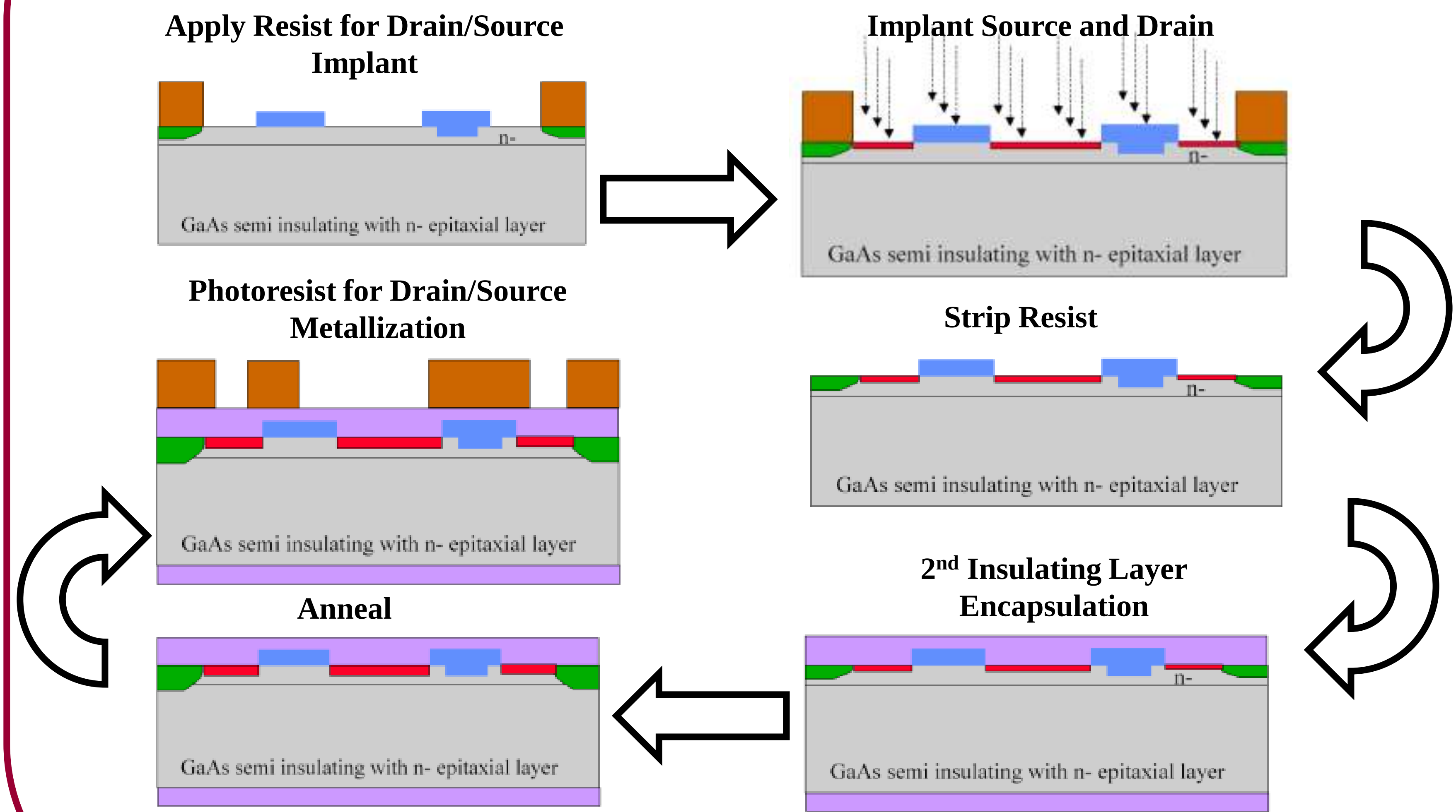


Deposit 3000 Å Tungsten

Liftoff Gate Forming Metal

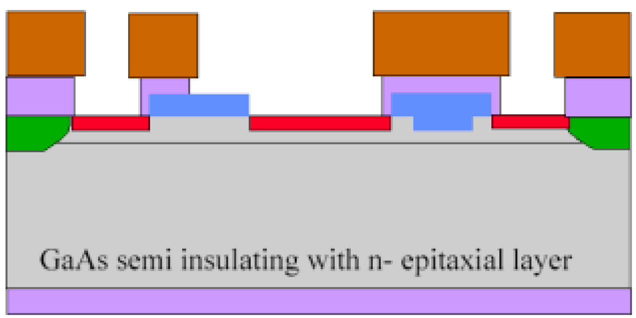
Etch Away Remaining Oxide

GaAs Processing

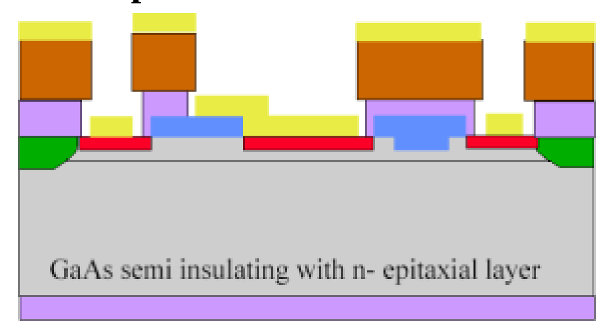


GaAs Processing

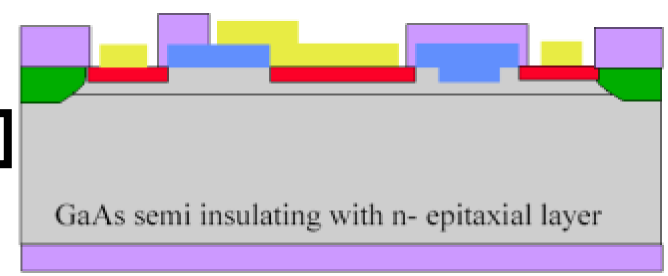
Etch Oxide



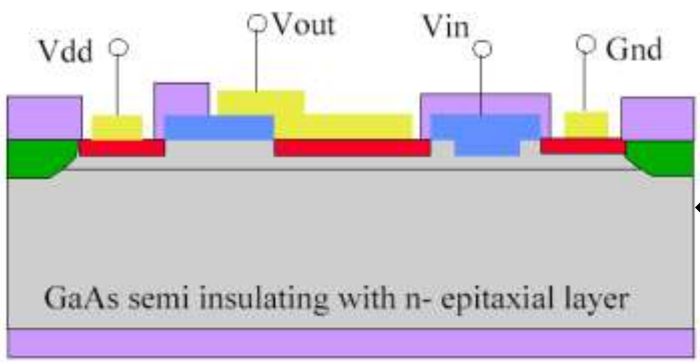
Evaporate Source/Drain Metal



Liftoff Resist



Add Connectors



Summary

GaAs has higher electron mobility giving devices with improved radio frequency performance or higher speed digital devices.

GaAs has different processing technology from silicon IC technology including: MBE, no oxide growth, encapsulation to prevent loss of arsenic at temperatures above 400 C.

The main semiconductor device made is the MESFET.

Optical LEDs and LASERs can be made in GaAs or related III-V semiconductors.