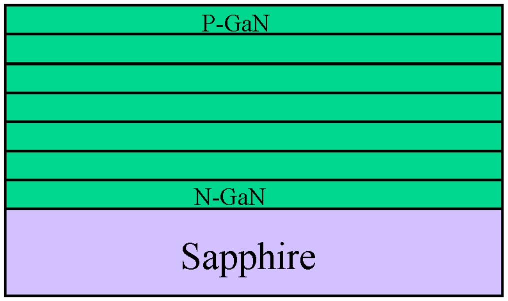
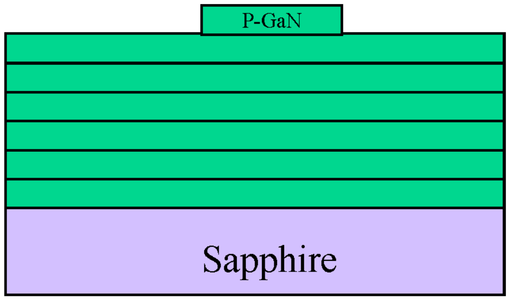
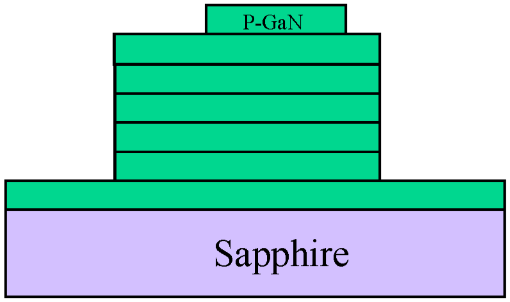
Process steps for laser diode fabrication



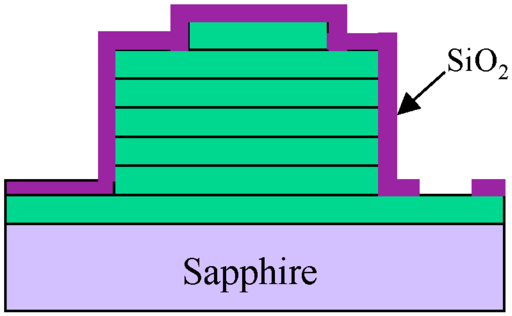
Laser structure



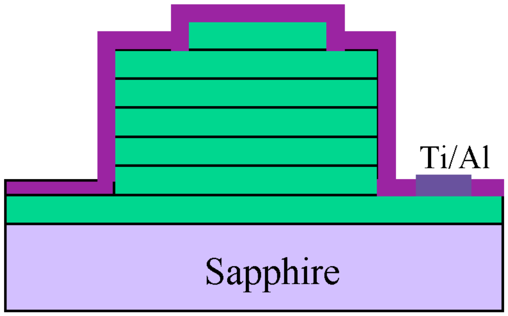
Ridge definition



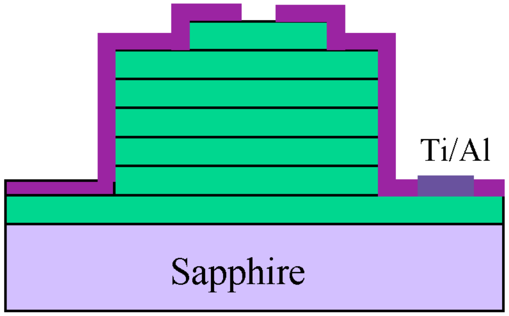
Stripe definition



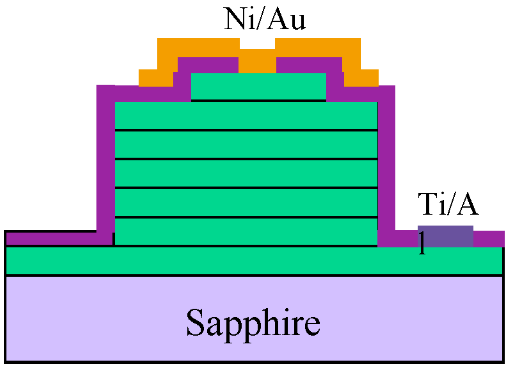
N-contact opening



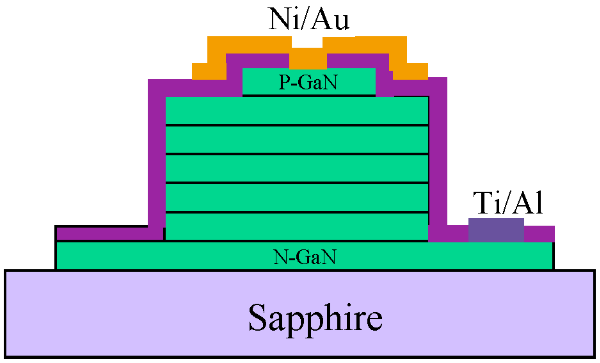
N-contact metal



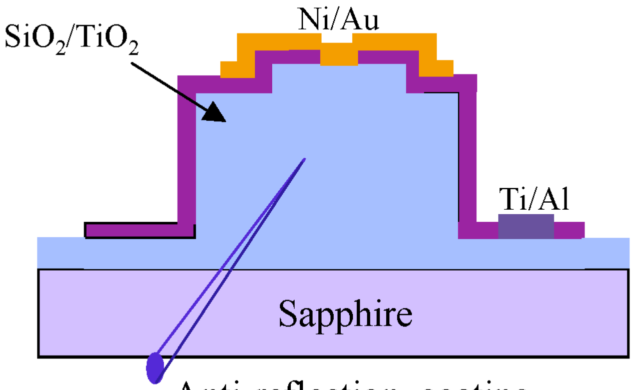
P-contact opening



P-contact metal



Mirror definition



Anti-reflection coating

Mechanisms of Etching

- Physical sputtering occurs at the lowest pressures (1 mTorr) and highest energies (keV). Non-selective.
- Chemical etching – selective, isotropic. Plasmas make reactive etchant species. Pressure 1 Torr.
- Ion-assisted etching via surface damage mechanism (point defects, dislocations, dangling bonds) takes place at lower energies and higher pressures (50 mTorr).
- Sidewall-protected – two different species: etchants and inhibitors
- Reactive ion etching – anisotropic etching

t PF Williams, Plasma processing of semiconductors

Inductive Coupled Plasma Etching

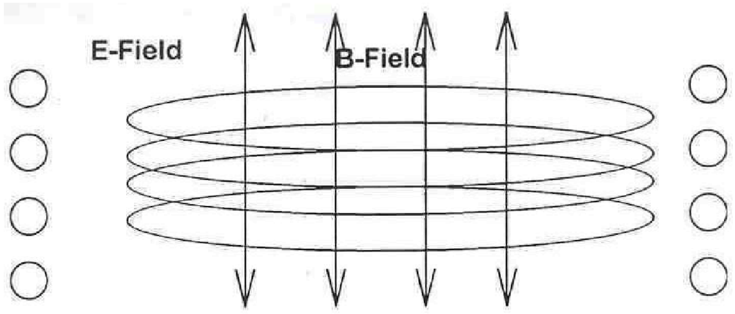
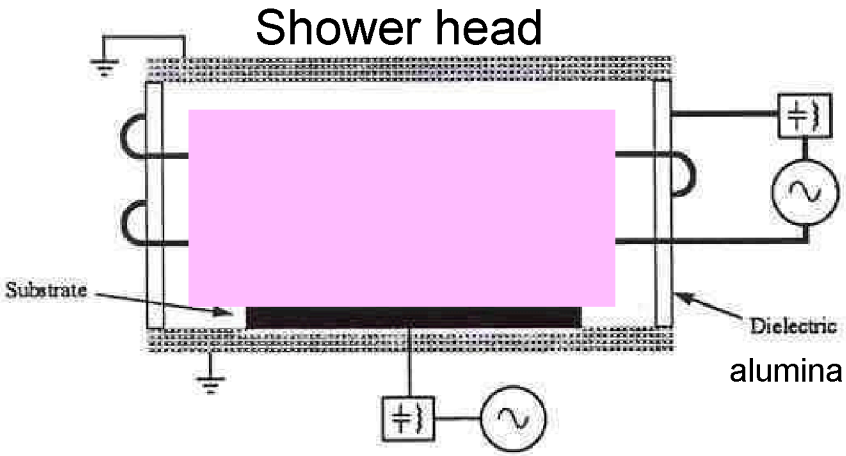


Figure 1



ICP pressure window 1 to 10 mTorr
1×10^{11} to 1×10^{12} cm^{-3}

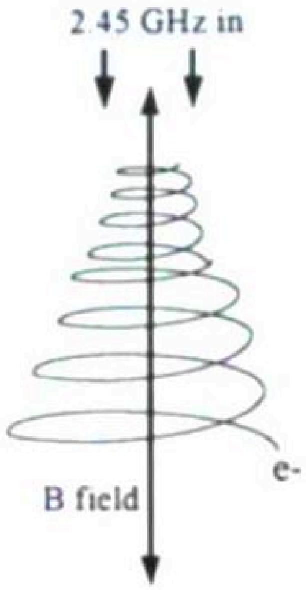
RIE pressure window 1 to 500 mTorr
1×10^{9} to 1×10^{10} cm^{-3}

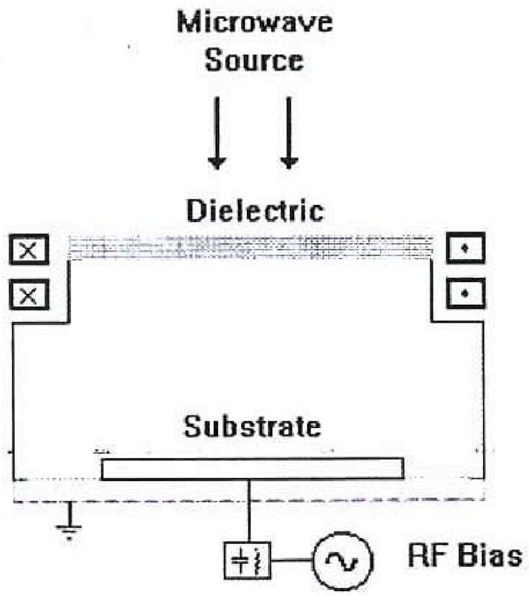
Electrons are heated by the E field that exists at right angles to the induced magnetic field. Power coupled through RF coil (1.7 to 2.1MHz)

The lower electrode is powered by by another RF source at 13.56 Mhz to allow for independent control of the substrate dc bias voltage.

In high density plasma etching systems, bombarding ion fluxes with current densities of 1 to 10 mA cm^{-2}, creates a sufficient concentration of reactive ions to devour the substrates

Electron cyclotron resonance reactor





Etching gases are Cl_2 and BCl_3

He backside cooling to control temperature of substrates

Electrons are heated by absorbing microwave energy at resonance due to the fact that the electron cyclotron frequency in an 875 Gauss magnetic field equals to the microwave frequency of 2.45 GHz. High plasma density can be achieved.

Conditions of a typical etch process for GaN

	Typical Etching Conditions	Allowable ranges
Gases	Cl_2, 20 sccm BCl_3, 8 sccm	Cl_2, 0 to 50 BCl_3, 0 to 50 Ar, 0 to 50 sccm
Temperature	25°C	-50°C to 150°C
Pressure	5mTorr	1 mTorr to 100 mTorr
ICP Power	400W	0 W to 1000 W
RIE Power	300W	50 W to 500 W

Inelastic collisions encountered by electrons ionise or excite neutral species in the plasma creating a reactive gas plasma

Dissociative attachment
$e + AB \rightarrow A^- + B^+ + e$

Dissociation
$e + AB \rightarrow e + A + B$

Ionization
$e + A \rightarrow A^+ + 2e$

Etch rate is about 0.2 μm / min

K Remashan et al, Sermicond. Sci. Techno. 15, p 386 (2000)

Considerations in dry etching

- For ICP working at low operating pressures, the excited plasma species are less susceptible to collisional recombination. So a high density is maintained at reasonable power levels.
- Additionally, ions are able to traverse the sheath above the substrate without multiple body collisions. This collisionless sheath permits ions to arrive normally to the surface being etched.
- The excited atoms and radicals form volatile compounds upon reacting with the substrate materials. The volatile compounds are pumped away continuously during etching. The species have different characteristics lifetimes
- The various species will not etch a given material at the same etch rate, Hence lies the origin of etch selectivity.
- Steps involved in plasma etching: (1) generation of reactive chemical species (2)diffusion or drift of species to film surface (3) adsorption of species on film surface (4) surface diffusion of active ions and radicals (5) chemical etching reactions (6) desorption of volatile reaction products and (7) transport of etching by-products to the plasma.

Silicon nitride formation

SiH_4 and NH_3 forms an intermediate precursor tetra-amino silane $Si(NH_2)_4$

$Si(NH_2)_4$ looses a NH_2 group to form $Si(NH_2)_3$

Sub-surface condensation of $Si(NH_2)_3$, with low sticking coefficient

SiN_xH_y forms with release of NH_3

- In the solid, Si-N bonds are stretched resulting in high tensile sress in the film (except at frequency < 1 MHz). Si_3N_4 may incorporate up to atm 30% of H.
- Si-rich nitride (low NH_3/SiH_4 ratio and high power to break N-H bond). Si-H bonds are broken by energetic electrons and trap electrons and produce internal field.
- N-rich nitride (high NH_3/SiH_4 ratio). Trapping rate of electron is low. NH and NH_2 are formed and they form a glassy network like SiO_2.

Silicon oxide formation

N_2O dissociates into N_2 and O upon electron impact.
$Si(OH)_4$ are formed like $Si(NH_2)_4$ precursor in silicon nitride formation
SiO_2 films are compressive
O_2 is not used to replace N_2O, as O reacts spontaneously with SiH_4 to form a powder.

Silicon oxynitride

$SiH_4 + NH_3 + N_2O \rightarrow SiO_xN_yH_z$
By adjusting the NH_3/N_2O ratio, the film stress can be made to be exactly zero.

Metal-semiconductor contacts

It is a fundamnetal element to all semiconductor devices. There are two types, viz. Schottky and ohmic contacts.

Schottky contacts – exhibit rectifying I-V characteristics, The impedance is dynamic in nature, usually high at low bias. Example of apploications: photodetectors, microwave mixers, MESFETS

Ohmic contacts – exhibits linear I-V characteristics with much smaller impedance that Schottky contacts. Example of applications: source and drain contacts in a FET, emitter, base and collector of bipolar transistors, contacts for LEDs and semiconductor lasers.

The must have good adhesion and withstand temperature cycling, low contact resistance, a shining surface and a wide process window for wire bonding (21 stitches per second).

FA Padovani, Semiconductor and Semimetals (Edt R.K Willardson and AC Beer), Vol 7, Chapter 2
LJ Brillson, Contacts to semiconductors.

Metallisation systems (GaAs)

n-type GaAs

-Ge(100)/Au(200)/Ni(300)/Au(600) nm; RTP 420°C/20s

The thickness of each element has to be optimised and the layer sequence is also important. Ge is responsible for doping the GaAs during alloying. Ni prevents the AuGe metal from ‘balling up’ to obtain a regula surface morphology. It also aids the diffusion of Ge into the GaAs, Too much nickel can cause the formation of Ni_2As which is more resistive than NiAs. Annealing in forming gas 15% H_2/85% N_2.

p-type GaAs

-Pt(300)/Au(100) nm ; Cr(25)/Au(200) nm

Cleaning of the semiconductor surface prior to metallisation is critical. Generally, cleaning with TCE, acetone, IPA, etch in HF 5s, DI rinse.

SJ Chua et al., Thin Solid Film, 200 (1991)
Jap. J. Appl. Phys., Vol. 33, (1994)
RE Williams, Gallium Arsenide Processing techniques

Metallisation systems (InGaAs)

$In_{0.53}Ga_{0.47}As$ is lattice matched to InP

For both p- and n-type $In_{0.53}Ga_{0.47}As$ Ti(20)/Pt(40)/Au(200) nm is used
However Pd has similar properties to Pt, Pd is also used

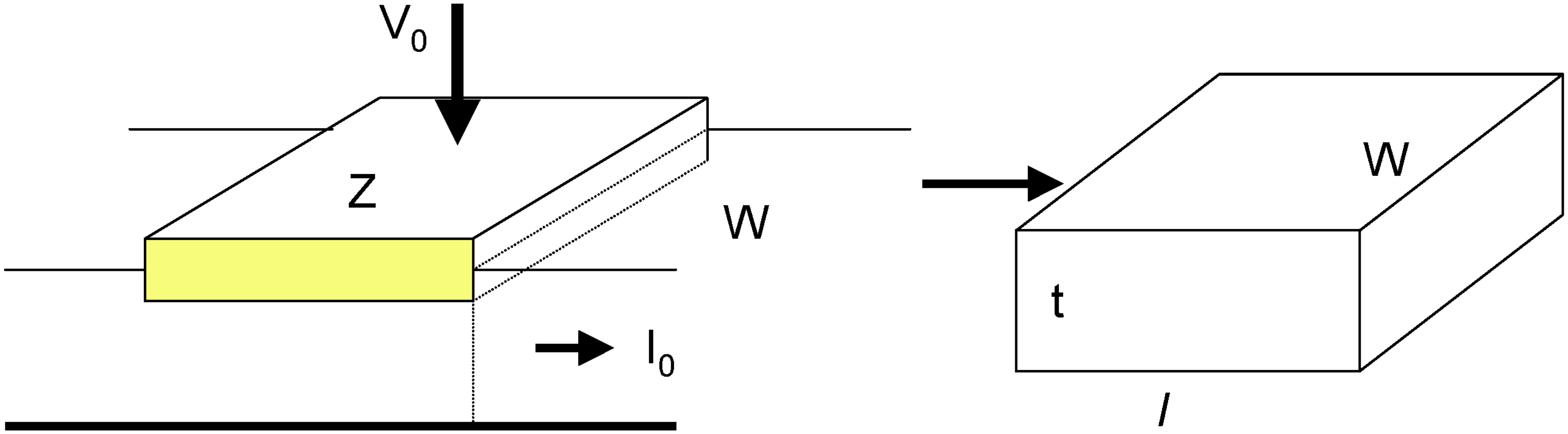
	Pd	Pt	
Melting point	1552	1769	°C
Resistivity	9.93	9.85	μΩ-cm
Work function	4.99	5.32	eV

Of the following
Ti(20)/Pd(20)/Au(200) nm and Pd(10)/Ti(20)/Pd(20)/Au(200) nm

a contacting of Pd is crucial to the formation of a low resistance contact.
RTA at 350 °C for 20s.

p-InGaAs (Be doped to $1\text{x}10^{18}\text{cm}^{-3}$) r_c – $1\text{x}10^{-5}$ $\Omega\text{-cm}^2$
n-InGaAs (Si doped to $5\text{x}10^{19}$ cm^{-3}) r_c – $8.5\text{x}10^{-7}$ $\Omega\text{-cm}^2$

Contact resistance



Contact resistance $R_c = \frac{V_0}{I_0}$

Resistance $R = \rho \frac{l}{tW} \quad ohm$

Contact resistivity or
Specific contact resistance

Sheet resistance $r_s = \frac{\rho}{t} \quad ohm/sq$

$$r_c = R_c A \quad ohm - cm^2$$

$$A = WZ$$

Transfer length method for contact resistance measurement

Resistance between to two adjacent contacts

$R_{n,n+1} = 2R_c + r_s(L_{n,n+1})/W$

y-intercept: $2R_c$ where

R_c = contact resistance

x-intercept: L_x where

L_x = Transfer Length

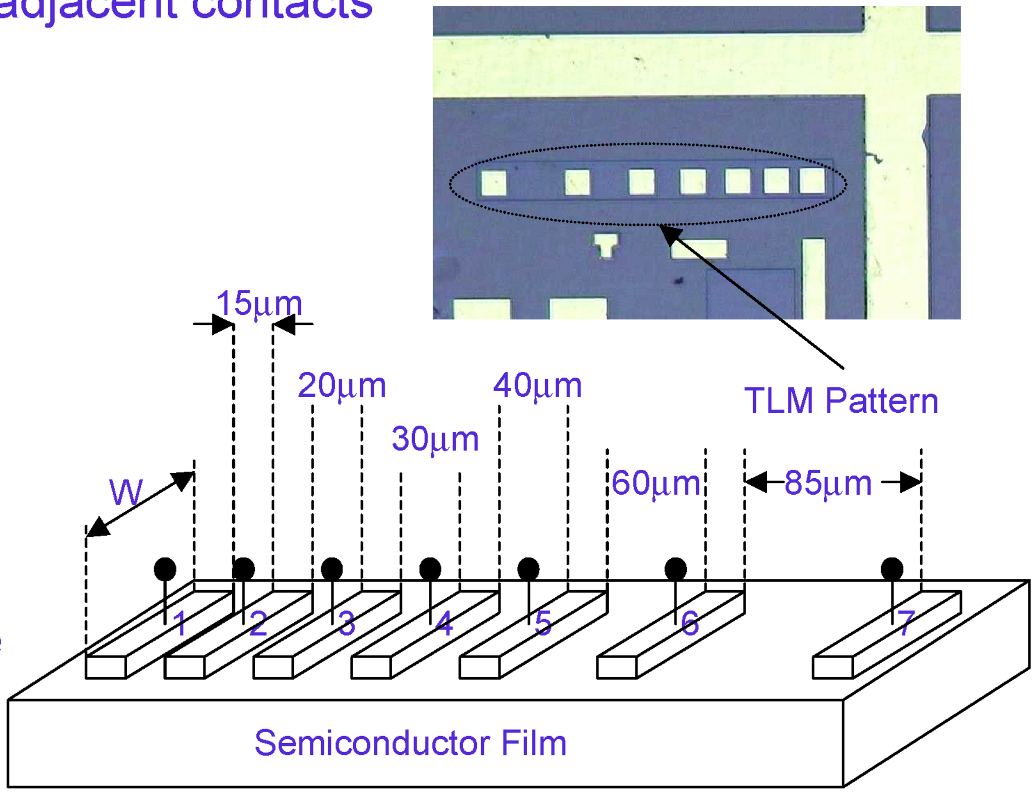
Gradient: r_s/W where

r_s = sheet resistance

$W = 40\mu m$ = Contact Width

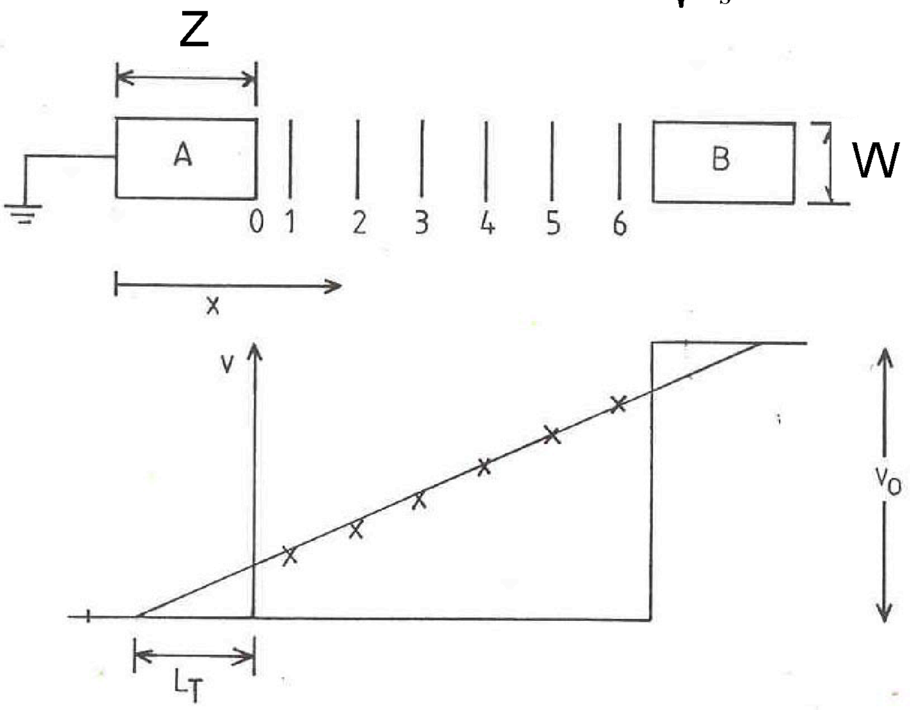
Specific Contact Resistance

$\rho_c = R_c^2 W/r_s$

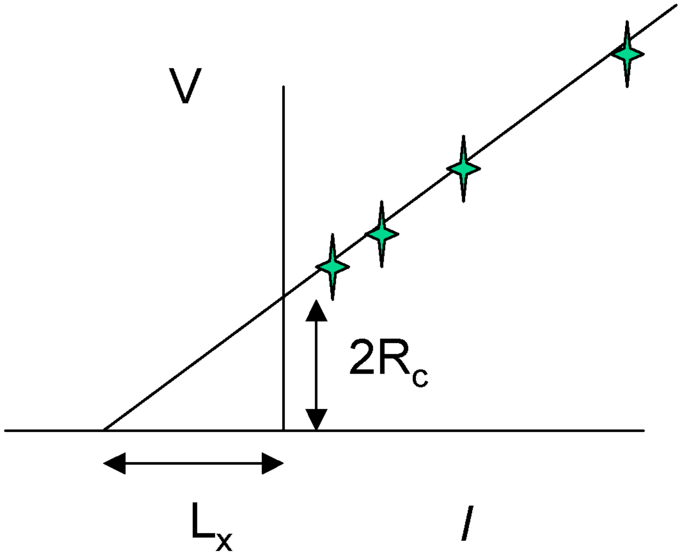


Transfer Length Method

Slope = $\frac{r_s}{W}$ $L_T = \sqrt{\frac{r_c}{r_s}}$



Contact Pads : A and B
Contact Strips : 1, 2, ----

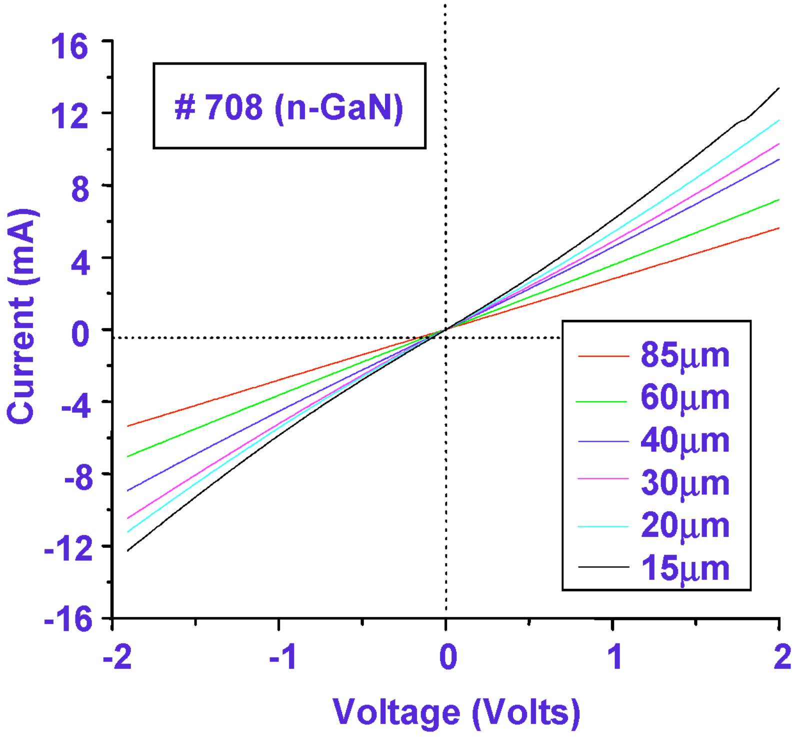


$L_x = 2 L_T$

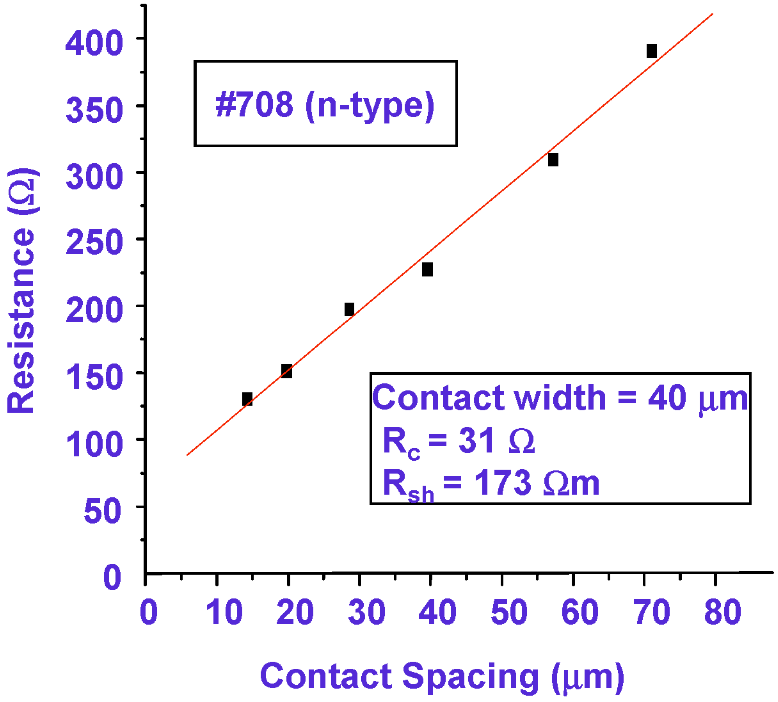
Metallisation systems (GaN)

Ti/Al Contact for n-GaN

Annealed at 550°C for 30s in N_2
- linear ohmic IV behaviour



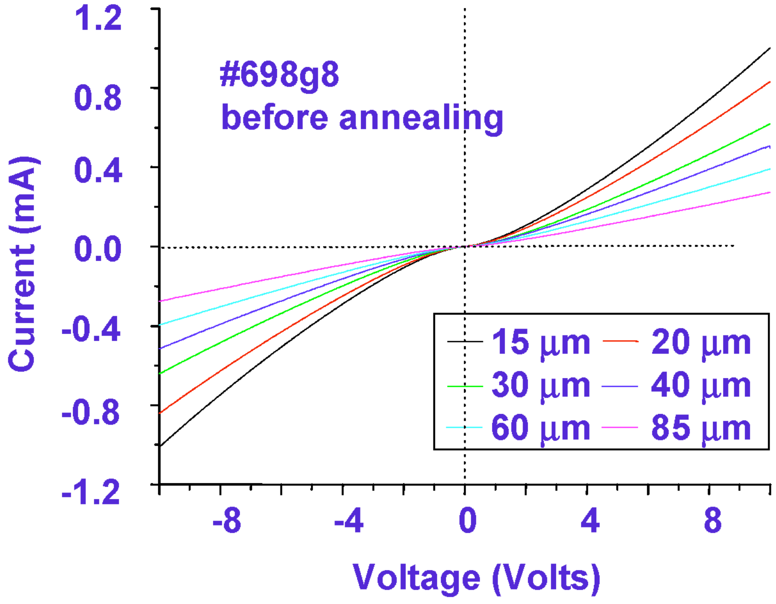
Specific contact resistance
= 7.0E-5 Ωcm²



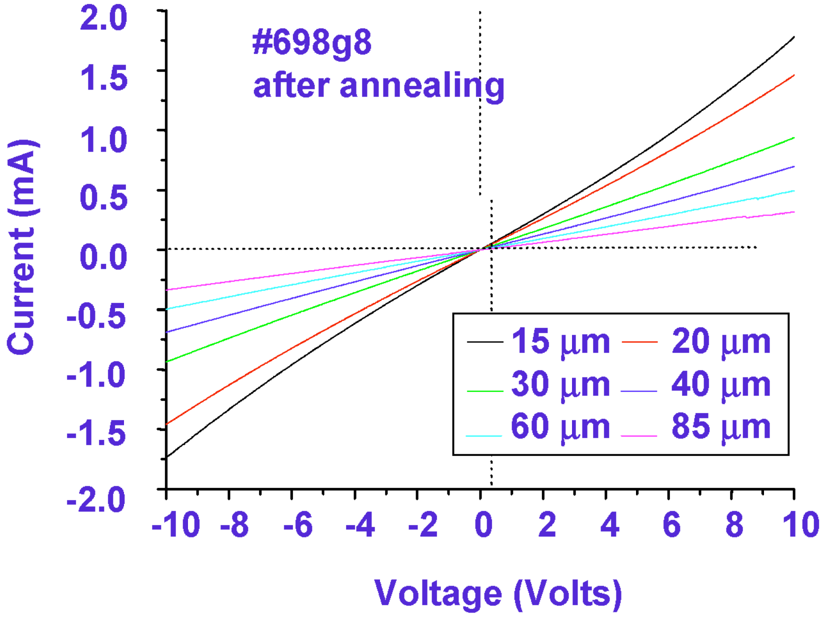
Metallisation systems (GaN)

Ni/Au Contact for p-GaN

Before annealing
- characterized as Schoktty-type
- built-in voltage: 1 - 3V



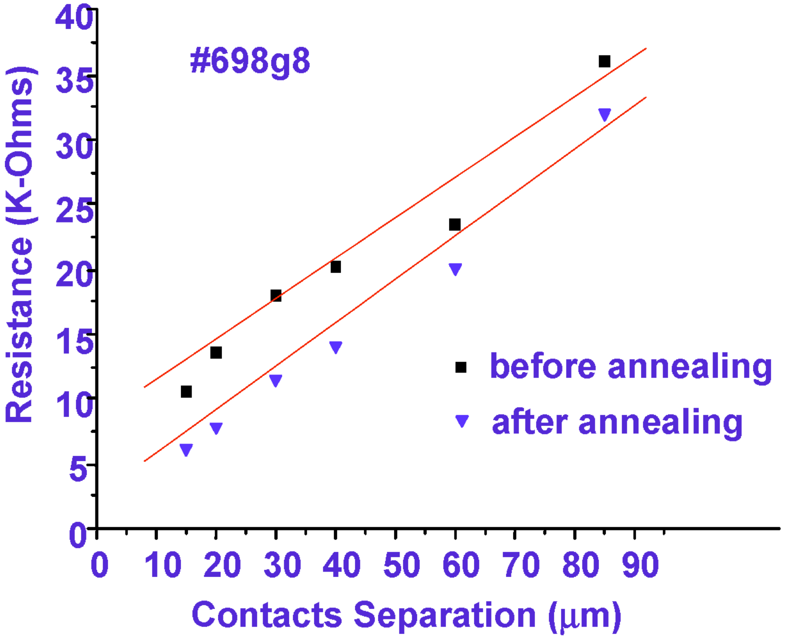
Annealed at 550°C for 12 min in air
- linear ohmic IV behaviour



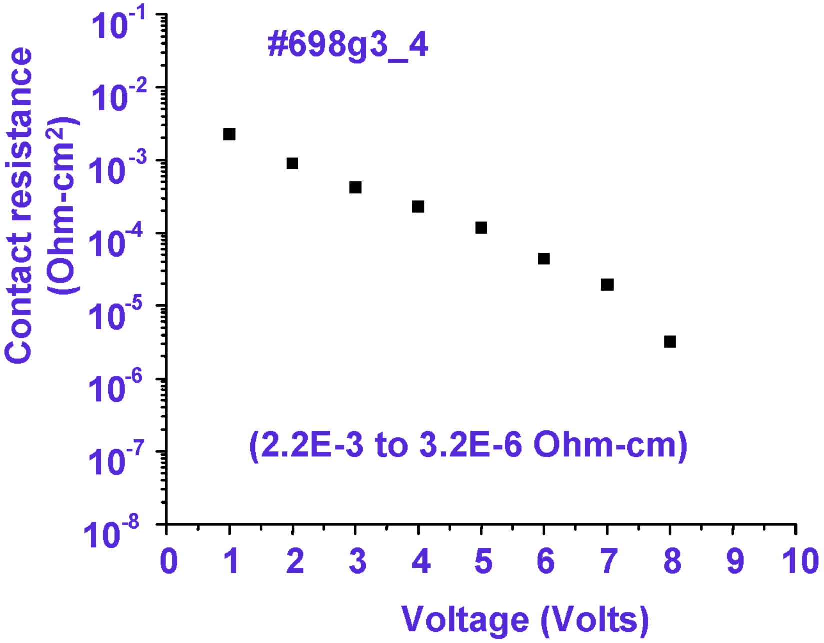
Metallisation system for p-GaN

Ni/Au Contact for p-GaN

before annealing: ρ_c = 1.247 x 10 $^{-2}$ Ω/cm
after annealing: ρ_c = 4.145 x 10^{-5} Ωcm

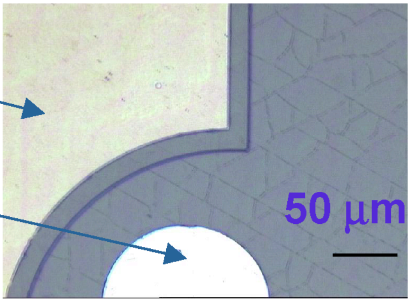


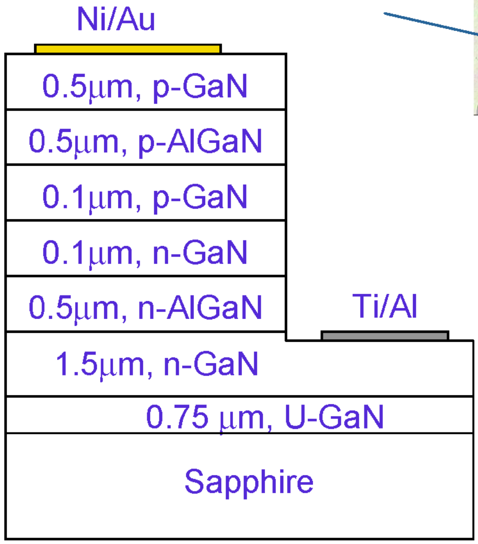
Variation in resistance as a function of applied voltages



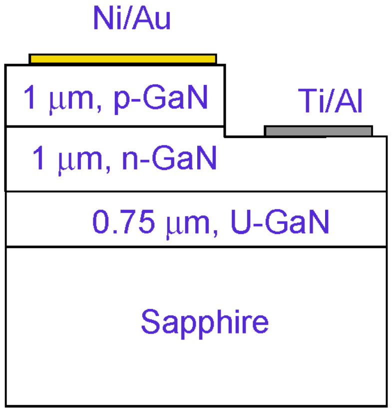
Device metal contacts

pn-junction





 # 758 (with AlGaN)



 # 757 (w/o AlGaN)