화합물 반도체 (III-3)
– n type ohmic contact

2007 / 가을 학기

Ohmic Contact to GaAs (I)

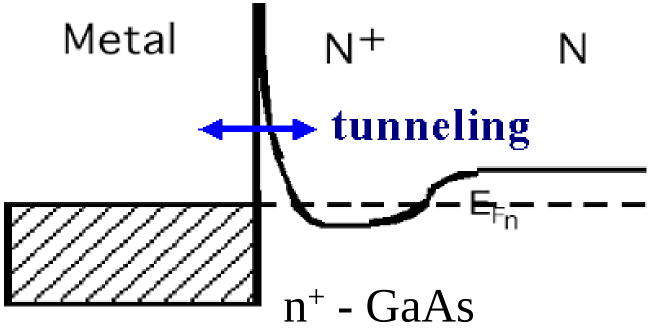
- **n-ohmic contact**

Au/Ge/Ni , Au-Ge/Ni <thin Au> ~2000Å

Au-Ge/Ni/ (Mo,Ti, Ag,W) /Au <thick Au> ~6000Å

bottom diffusion barrier thick/prevent oxidation

→ Ge이 GaAs에 diffusion하여 표면 n+영역 형성



tunneling ohmic contact

$$r_c = \left.\frac{\partial V}{\partial J}\right|_{V=0} \propto Exp\left[\frac{4\pi\phi_b}{h}\left(\frac{\varepsilon m^*}{N_d}\right)^{\frac{1}{2}}\right]$$

***(Au-Ge) ohmic contact 의 문제점**

→ 열처리 온도 (alloy temp, ~400˚C)에서 Au-Ge melt

Metal penetration / side reflow 발생(얇을수록 적게 나타남)

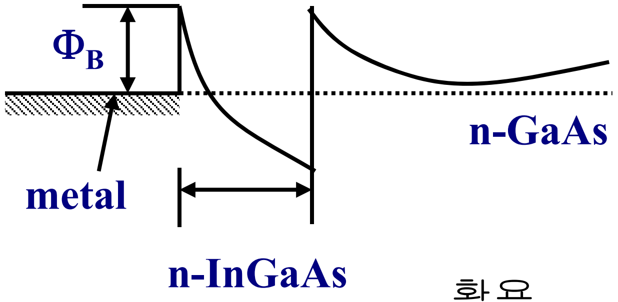
➡

- Thin Au-Ge 필요.
- 열처리 후 metal ball-up 발생(surface가 나빠짐)
- Reliability 문제

Ohmic Contact to GaAs (II)

*** thermally reliable ohmic contact**

i) Epi를 키운다. (n^+ 형성도 가능)

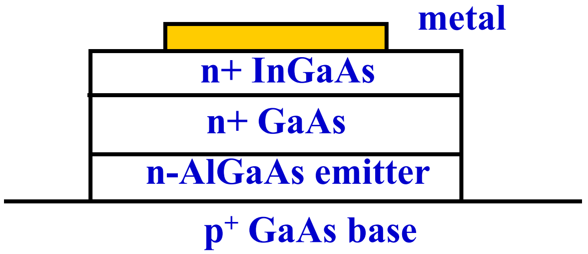


- Φ_B on $In_{0.53}GaAs$ ~ 0.2V

Metal 과 n-GaAs 사이에 Schottky barrier가 매우 작은 물질(InGaAs, InAs)를 넣어준다.

활용

GaAs HBT의 Emitter contact - small RC 필요



ii) In을 포함하는 metal alloy 형성

In/Ge/W 100Å /300Å /200Å

thin

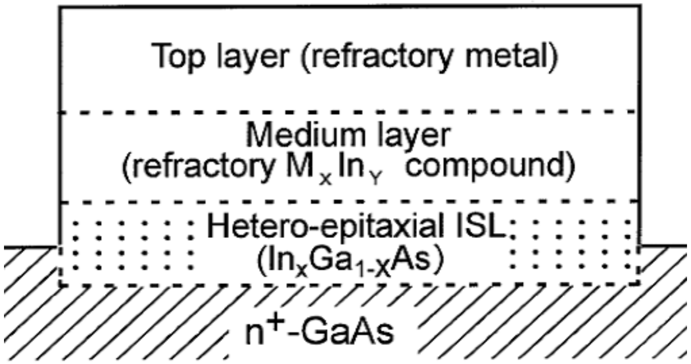
In/Ge/Ni /W

Metal 중 가장 높은 온도까지 견딘다.

(W, WN, WSi, WSiN)

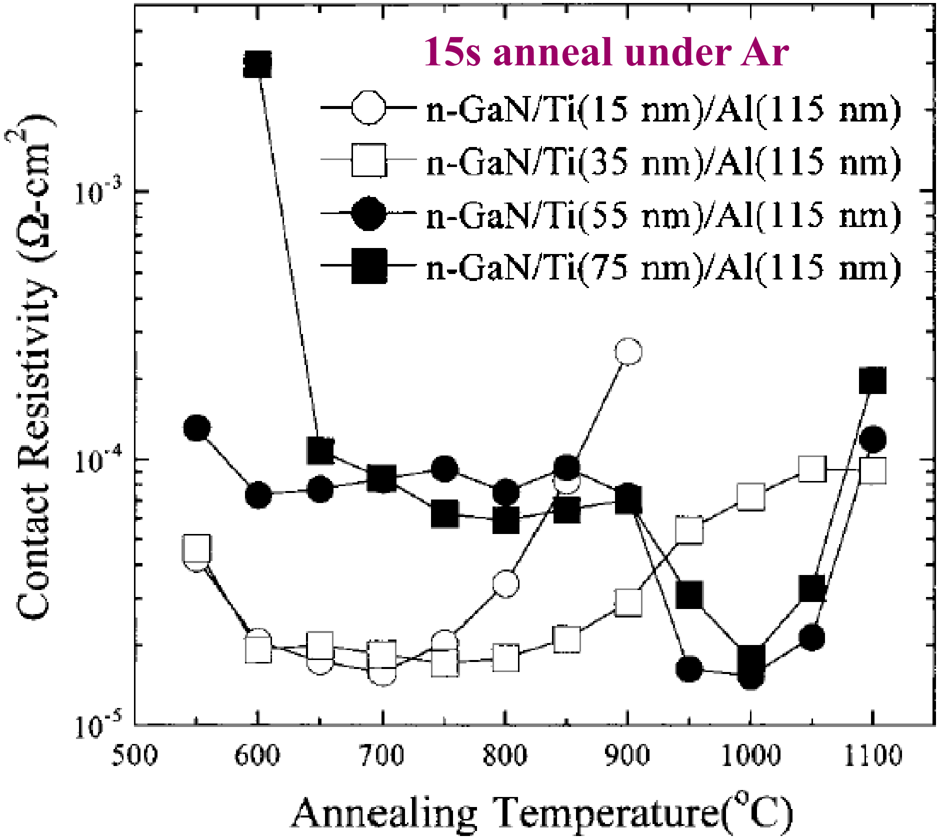
Ref : M, Murakami, Sci. & Tech. Adv. Mat., p. 1-27, 2002

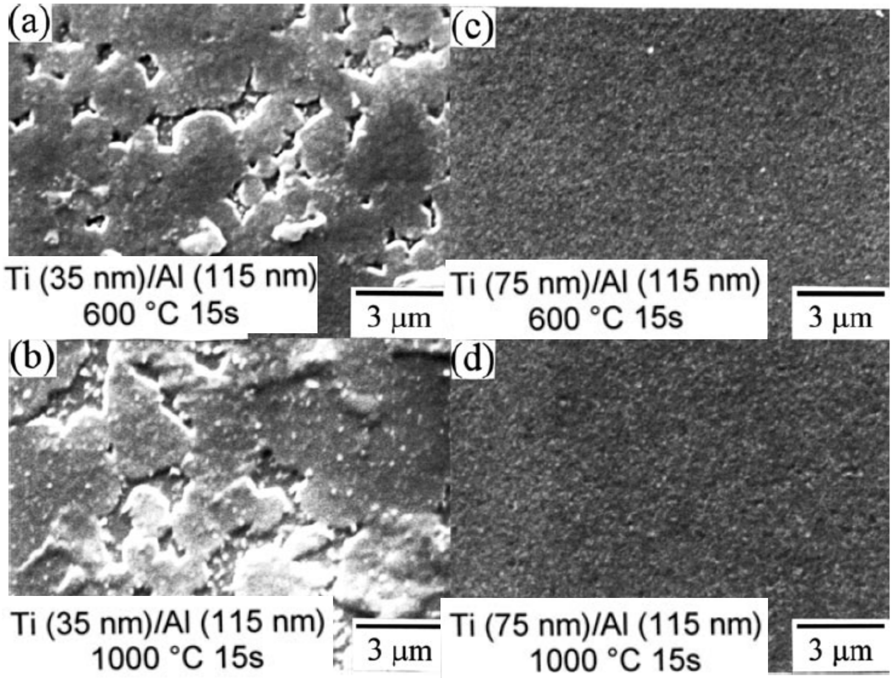
Ideal In-based Ohmic Contact



Ti/Al Ohmic Contact for n-GaN : Ti/Al Ratio (I)

- Ti/Al ohmic metals to MOCVD-grown n-GaN ($5x10^{16}cm^{-3}$)
  - **⇨ N-vacancy due to TiN (& AlN) formation ; n^+ surface layer**
- Rapid thermal annealed under Ar purified through Ti-getter furnace

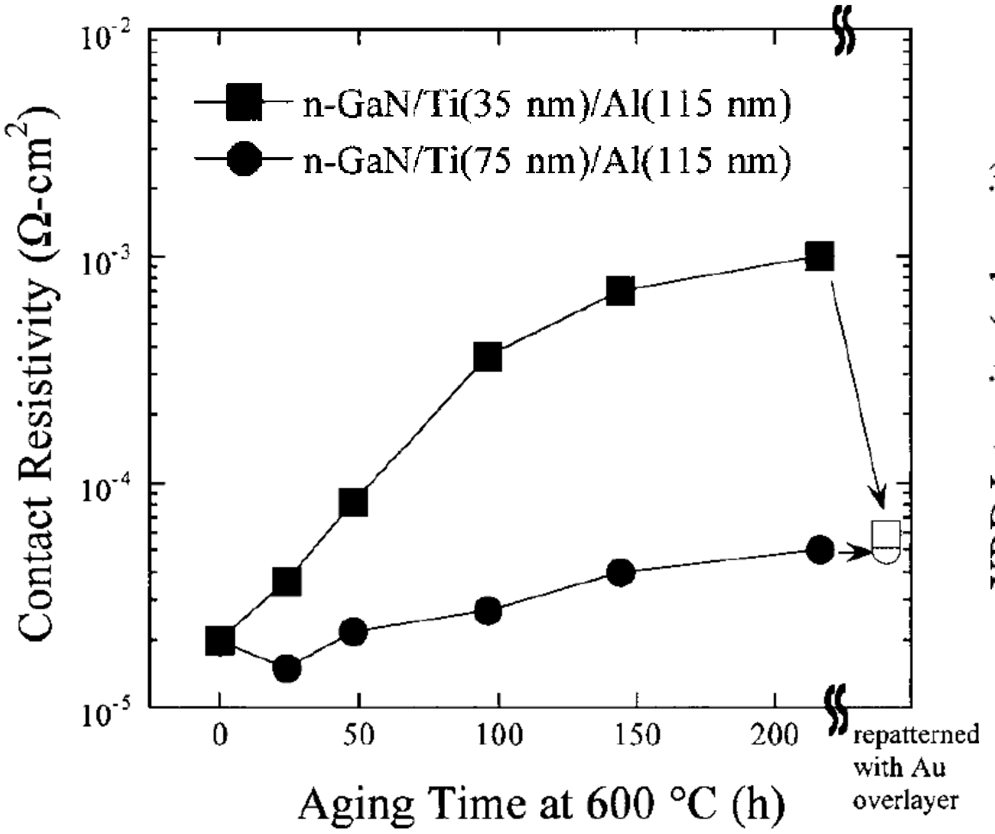


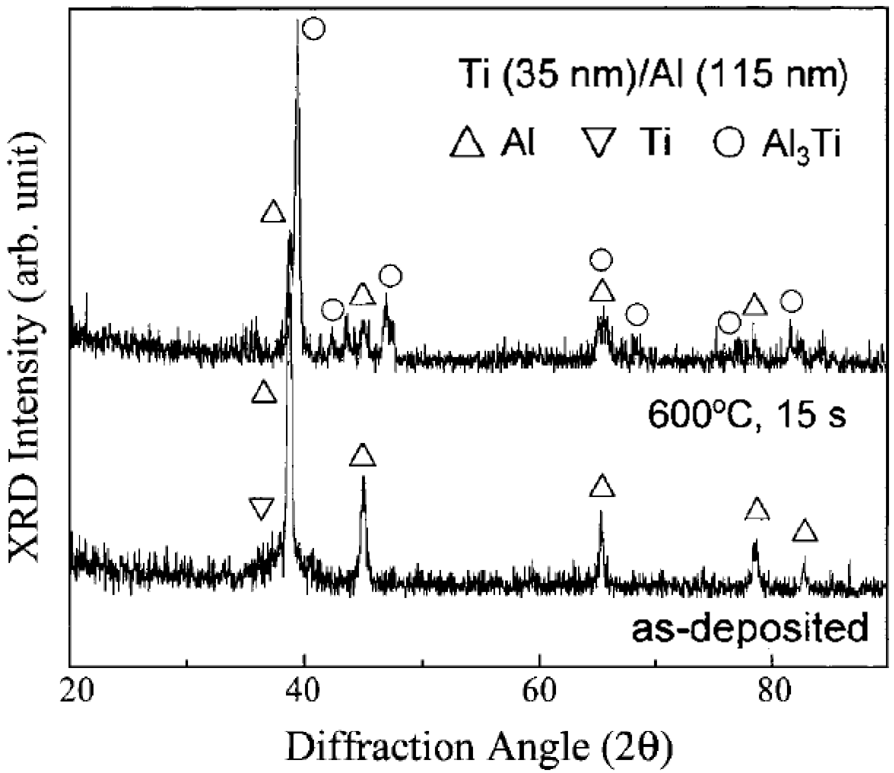


thick Ti ⇨ better morphology

Ref : J. S. Kwak, et al., Semicond. Sci. Technol. p. 756, 2000

Ti-Al Ohmic Contact for n-GaN : Ti/Al Ratio (II)





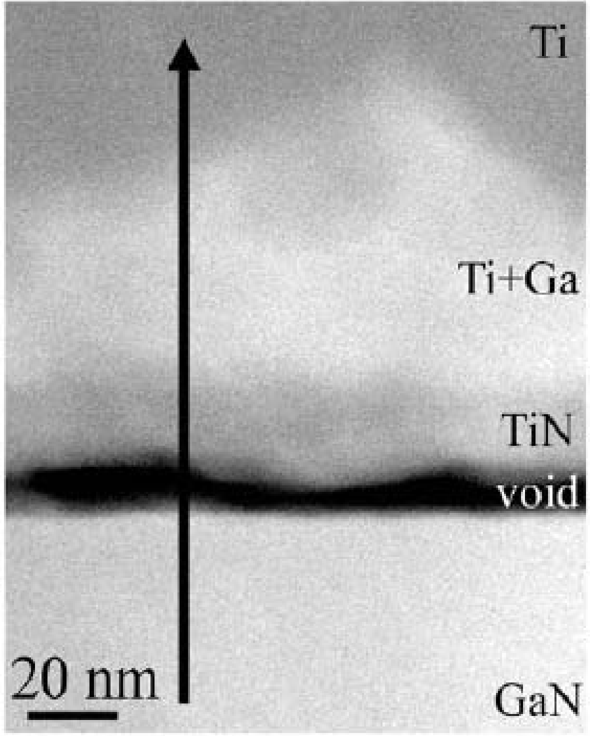
- Better thermal reliability with thick Ti
- Thin Ti contact gives increased metal sheet resistance with aging time.

- Thin Ti contact yields unreacted Al left after alloying ⇨ poor surface morphology & poor aging characteristics

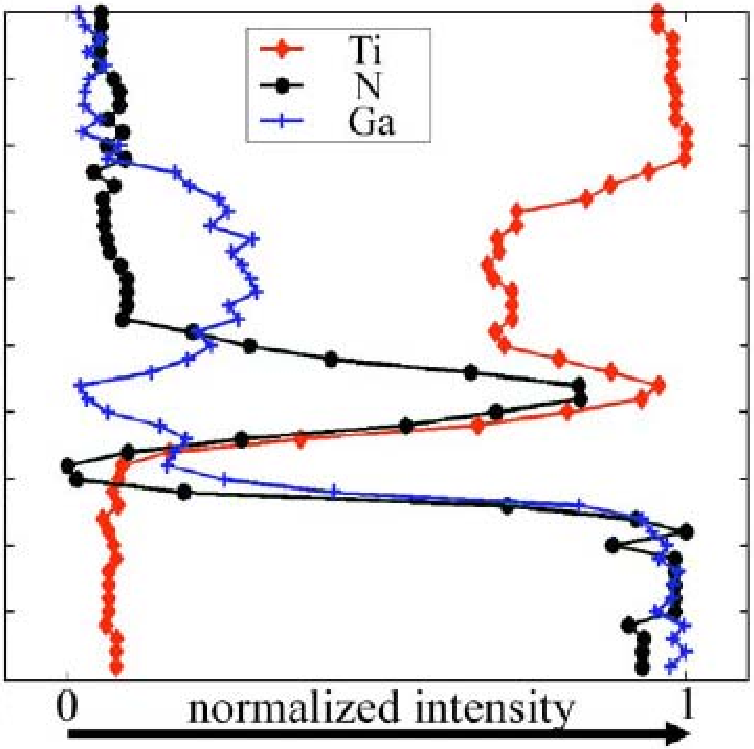
Ti Ohmic Contact to n-GaN - without Al Layer

Void formation with strong Ti reaction with GaN
⇨ Liquid Ga alloys with Ti (Ti-Ga Alloy).
⇨ Al slows down Ti reaction with GaN by forming $TiAl_3$ alloy.

200nm Ti rapid thermal annealed under N_2 up to 805-991°C

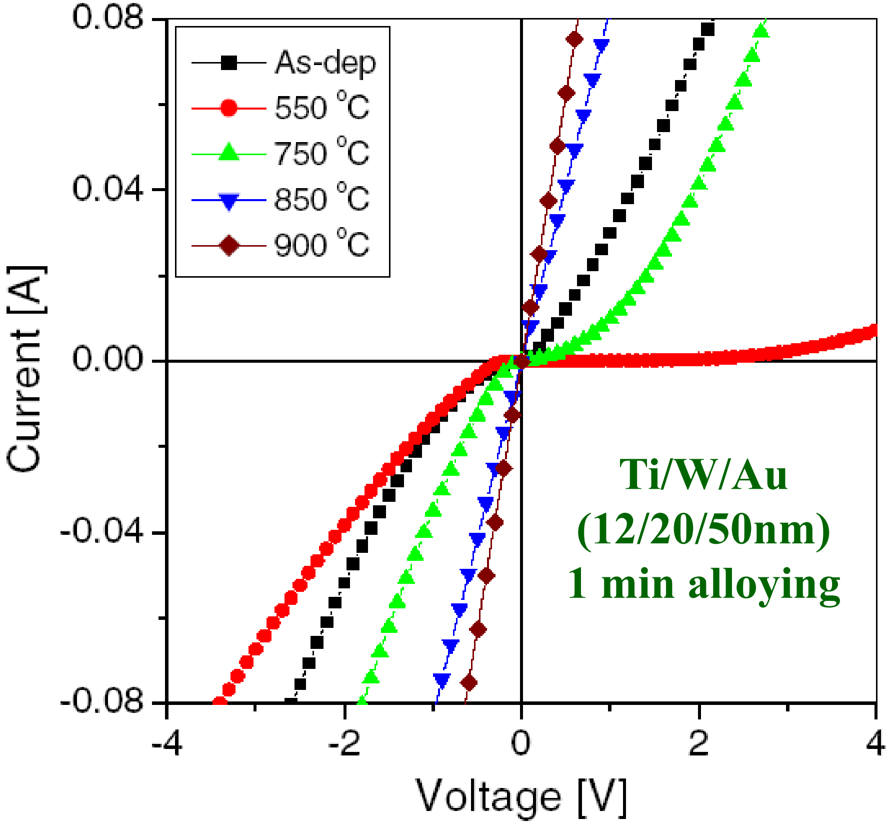


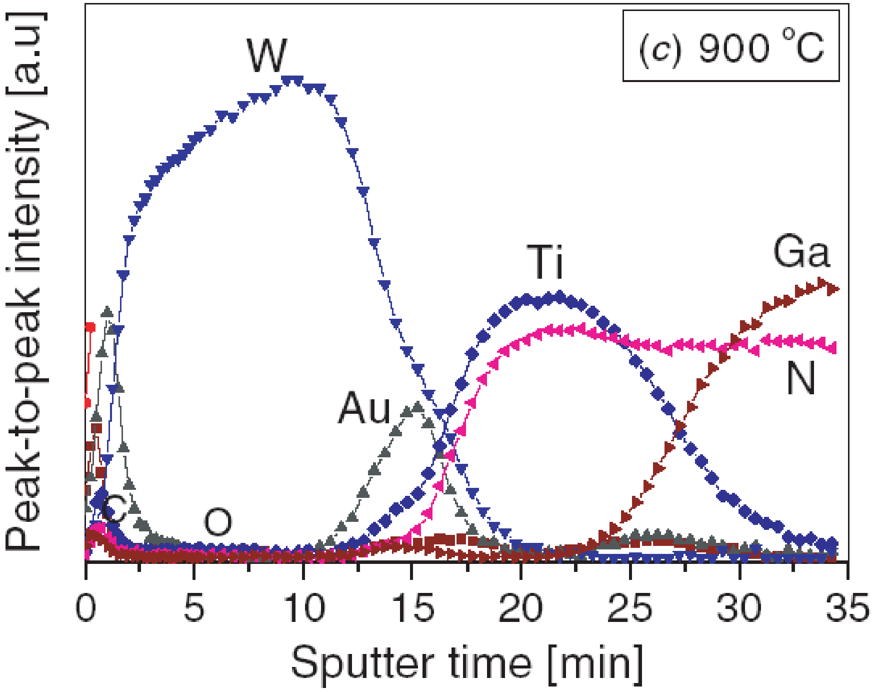
Analytical TEM Analysis - EELS Profile (Electron Energy Loss Spectroscopy)



Ref : B. Van Daele, et al., App. Phys. Lett. 87, 061905, 2005

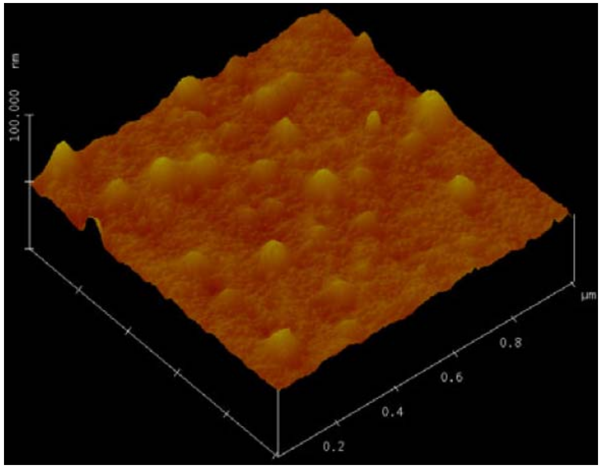
Ti/W/Au Contact to n-GaN - without Al Layer





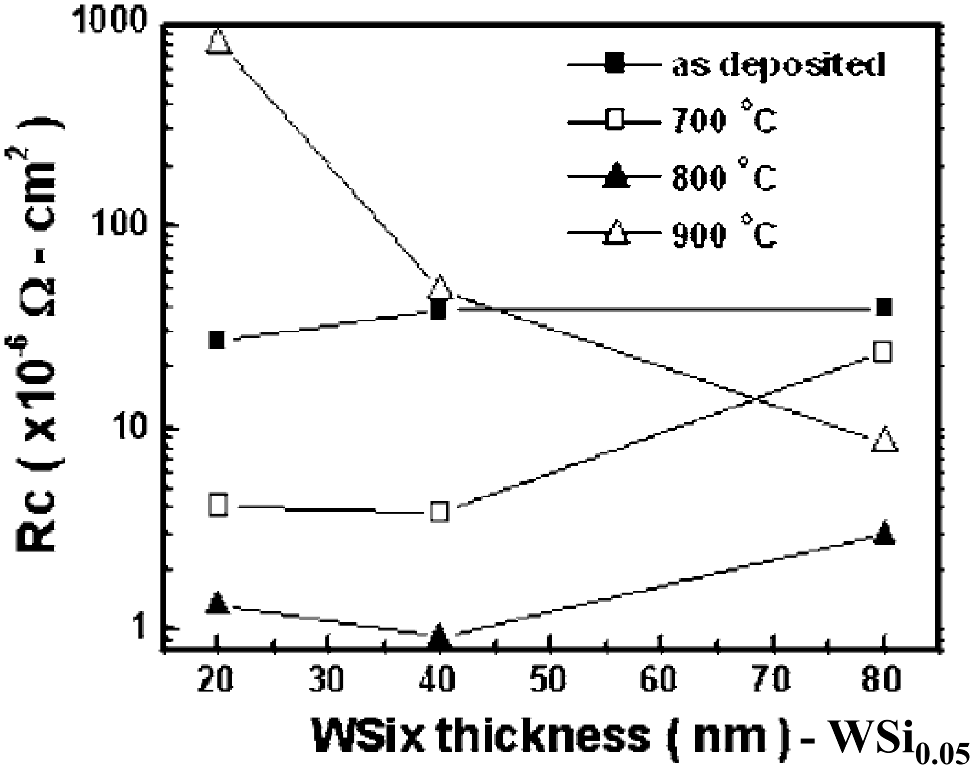
E-Beam Evaporated Ti/W/Au to n-GaN (4x$10^{18}$$cm^{-3}$)

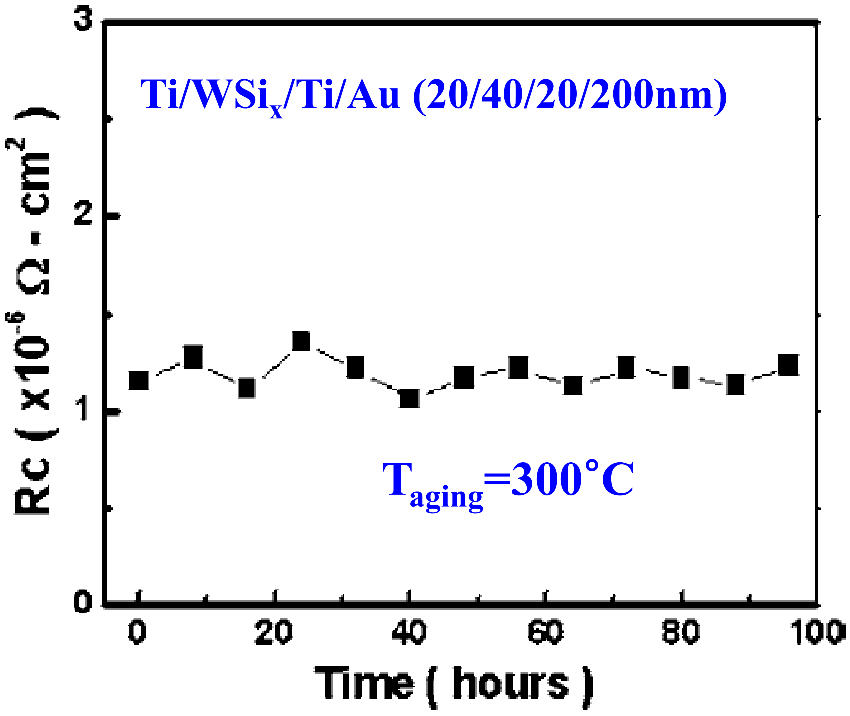
- ρ_C=8.4x10^{-6} Ωcm^2, 3.8 nm RMS roughness after 900°C, 1 min alloying
- BOE 1 min. dipping & blow-dry before metallization



Ref : V. R. Reddy, et al., Semicond. Sci. Technol., p. 975, 2004

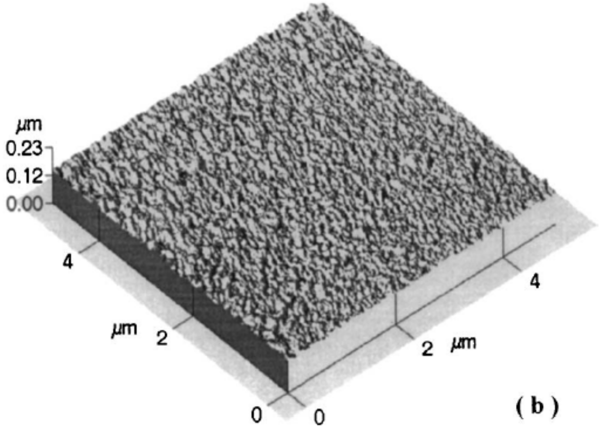
Ti/WSi/Ti/Au Contact to n-GaN - without Al Layer





Ti/WSi/Ti/Au Contact to n-GaN (2.2x10^{18}cm^{-3})

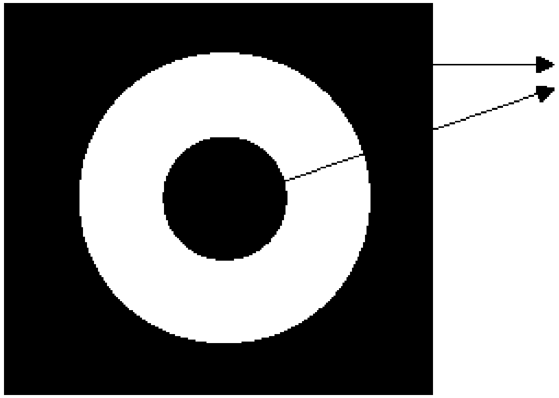
- 7.3 nm roughness after 800 °C, 3 min alloying



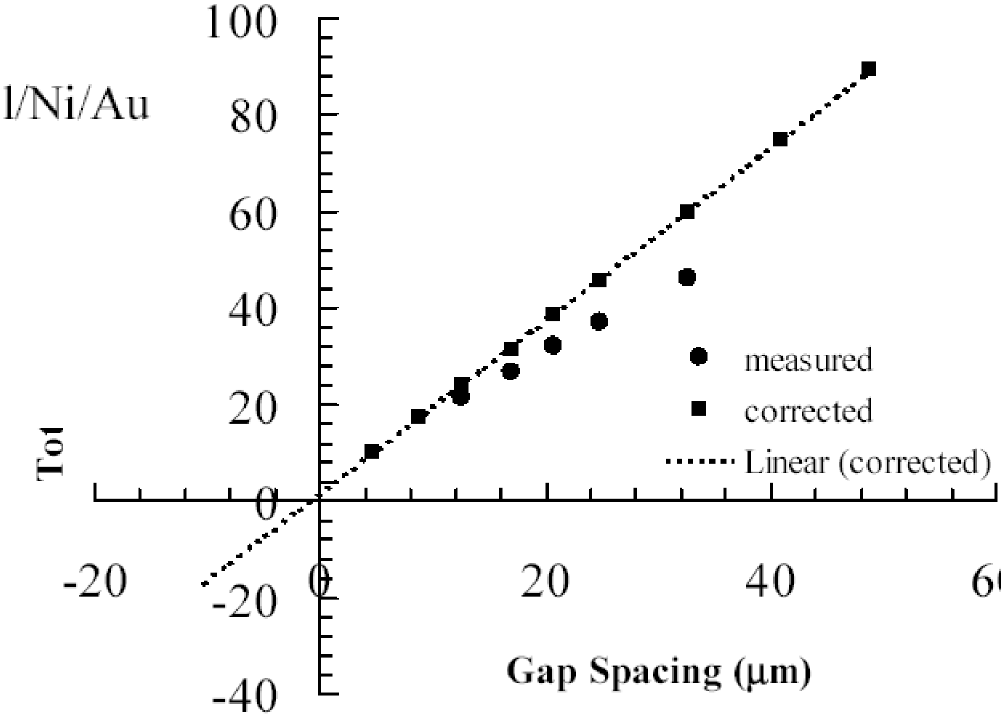
Ref : C.-C. Pan, et al., J. App. Phys. 98, 013712, 2005

Ohmic for n-AlGaN/GaN (I) : Ti-Al-Ni-Au

Modified Transfer Length Method
With different metal gap



Ref : B. Jacobs, et al., J. Crystal Growth, p. 15. 2002



AlGaN/GaN HEMT Structure

5nm n.i.d. $Al_{0.25}GaN$ contact layer
10nm $Al_{0.25}GaN$ ($1x10^{19}cm^3$ Si-doped)
3nm n.i.d. $Al_{0.25}GaN$ separation layer
2µm n.i.d. GaN buffer layer
40 nm AlN nucleation layer

$$R = \frac{R_{sh}}{2\pi}\left[\frac{L_t}{R_0}\frac{I_0(R_0/L_t)}{I_1(R_0/L_t)} + \frac{L_t}{R_1}\frac{K_0(R_1/L_t)}{K_1(R_1/L_t)} + \ln\left(\frac{R_1}{R_0}\right)\right]$$

Ohmic for n-AlGaN/GaN (II) : Ti-Al-Ni-Au

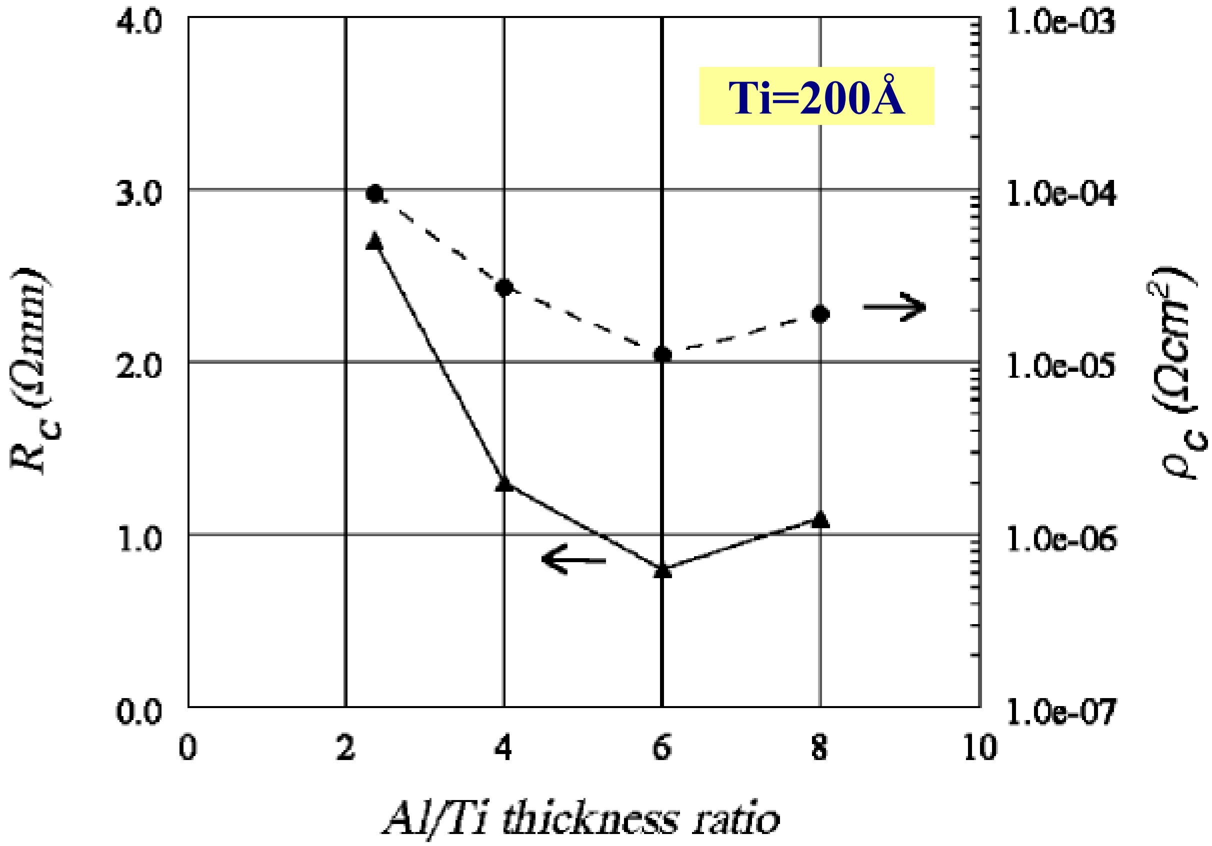


Fig. 3. R_c and ρ_c vs. Al/Ti thickness ratio; Ni = 400 Å, Au = 1500 Å; RTA 900°C for 30 s, N_2 ambient.

Ohmic for n-AlGaN/GaN (III) : Ti-Al-Ni-Au

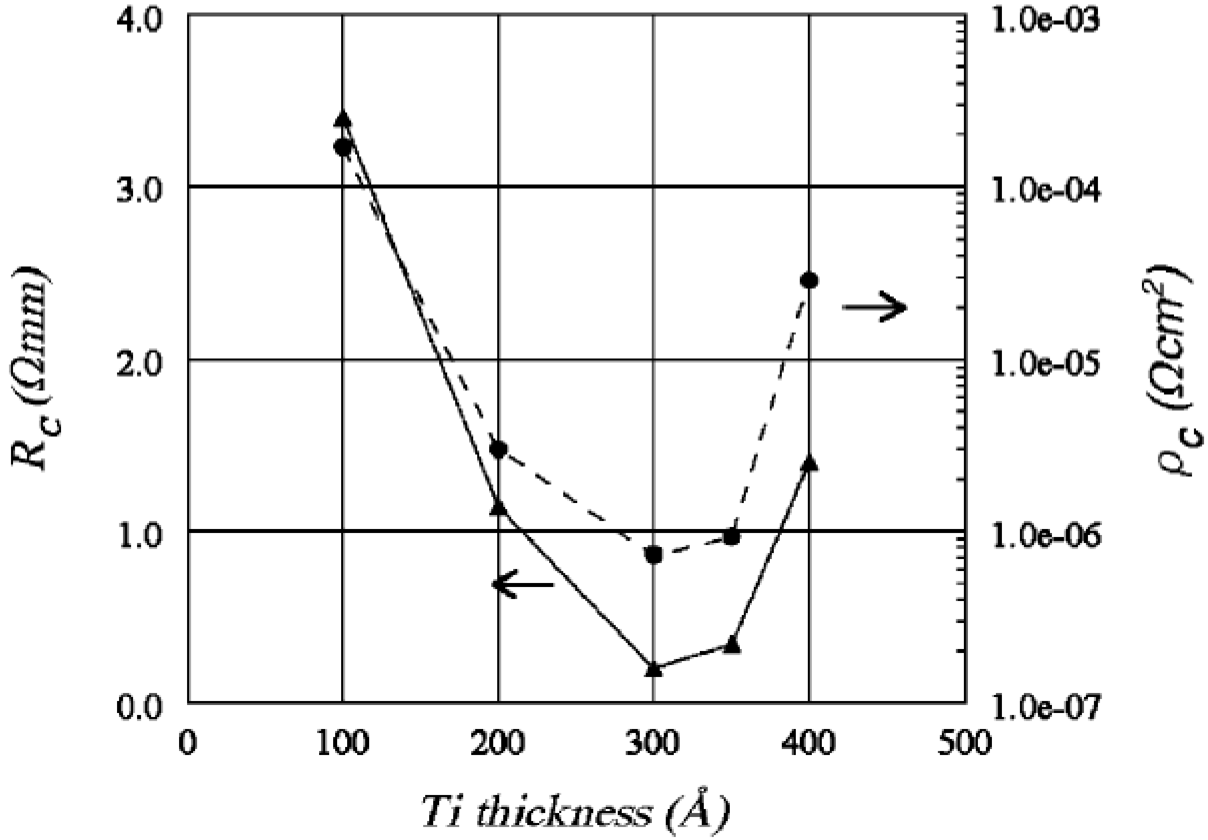


Fig. 4. R_c and ρ_c vs. Ti thickness; Al/Ti = 6, Ni = 400 Å, Au = 1500 Å; RTA 900°C for 30 s, N_2 ambient.

Ohmic for n-AlGaN/GaN (IV) : Ti-Al-Ni-Au

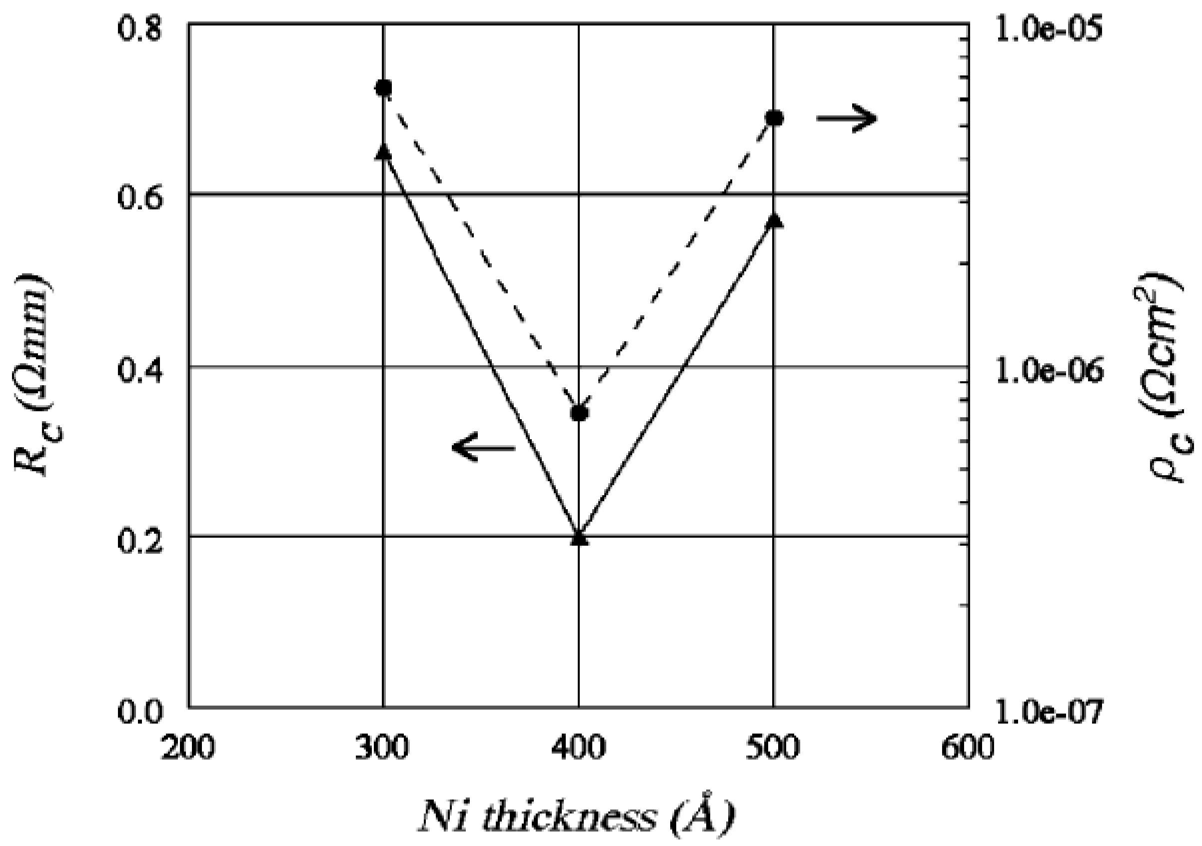
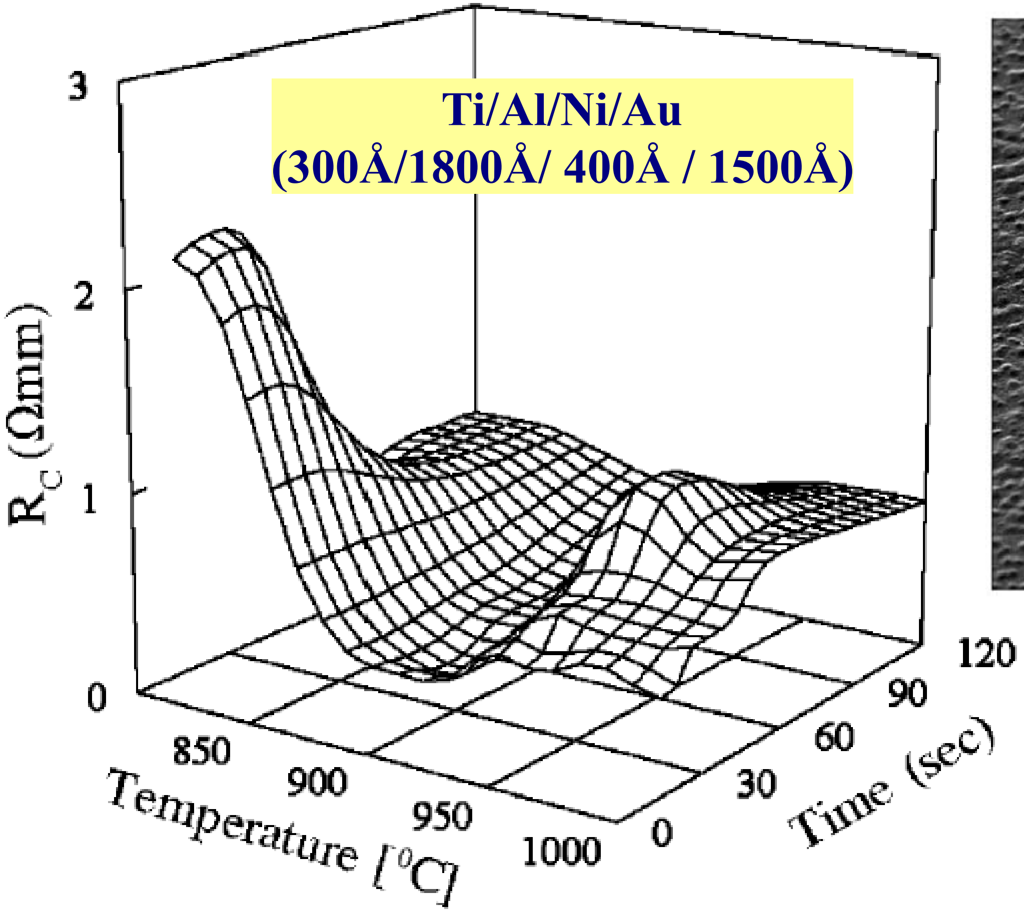


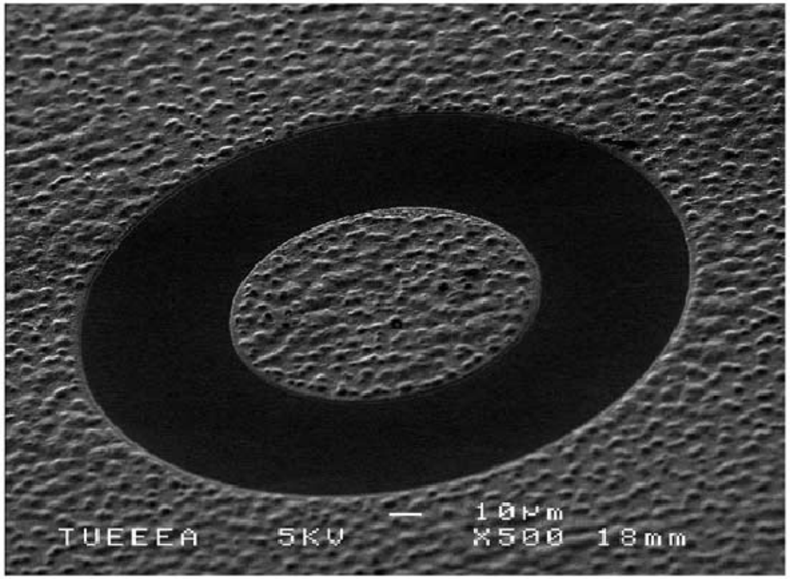
Fig. 5. R_c and ρ_c vs. Ni thickness; Ti = 300 Å, Al = 1800 Å, Ni + Au = 1900 Å; RTA 900°C for 30 s, N_2 ambient.

Ohmic for n-AlGaN/GaN (V) : Ti-Al-Ni-Au



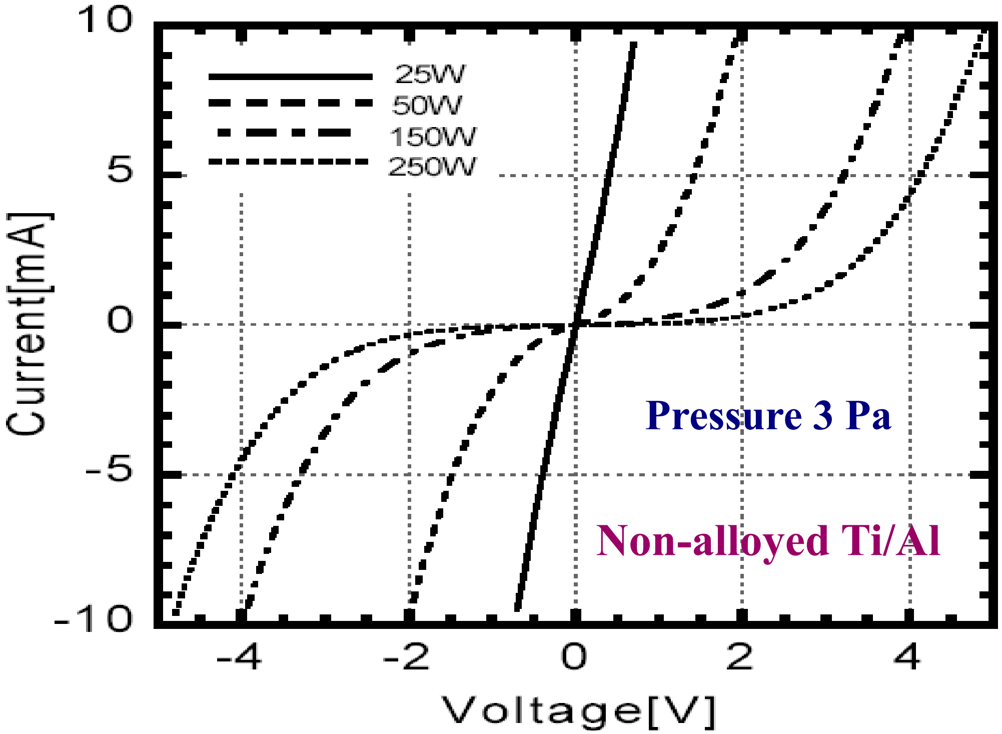
Ti/Al/Ni/Au
(300Å/1800Å/ 400Å / 1500Å)

Fig. 6. RTA tests for optimal R_c under N_2 ambient.



Ball-ups after alloying

Ti/Al contacts on BCl_3 RIE-etched n-GaN



Pressure 3 Pa

Non-alloyed Ti/Al

Low RF Power ⇨ Ohmic

High RF Power ⇨ Schottky

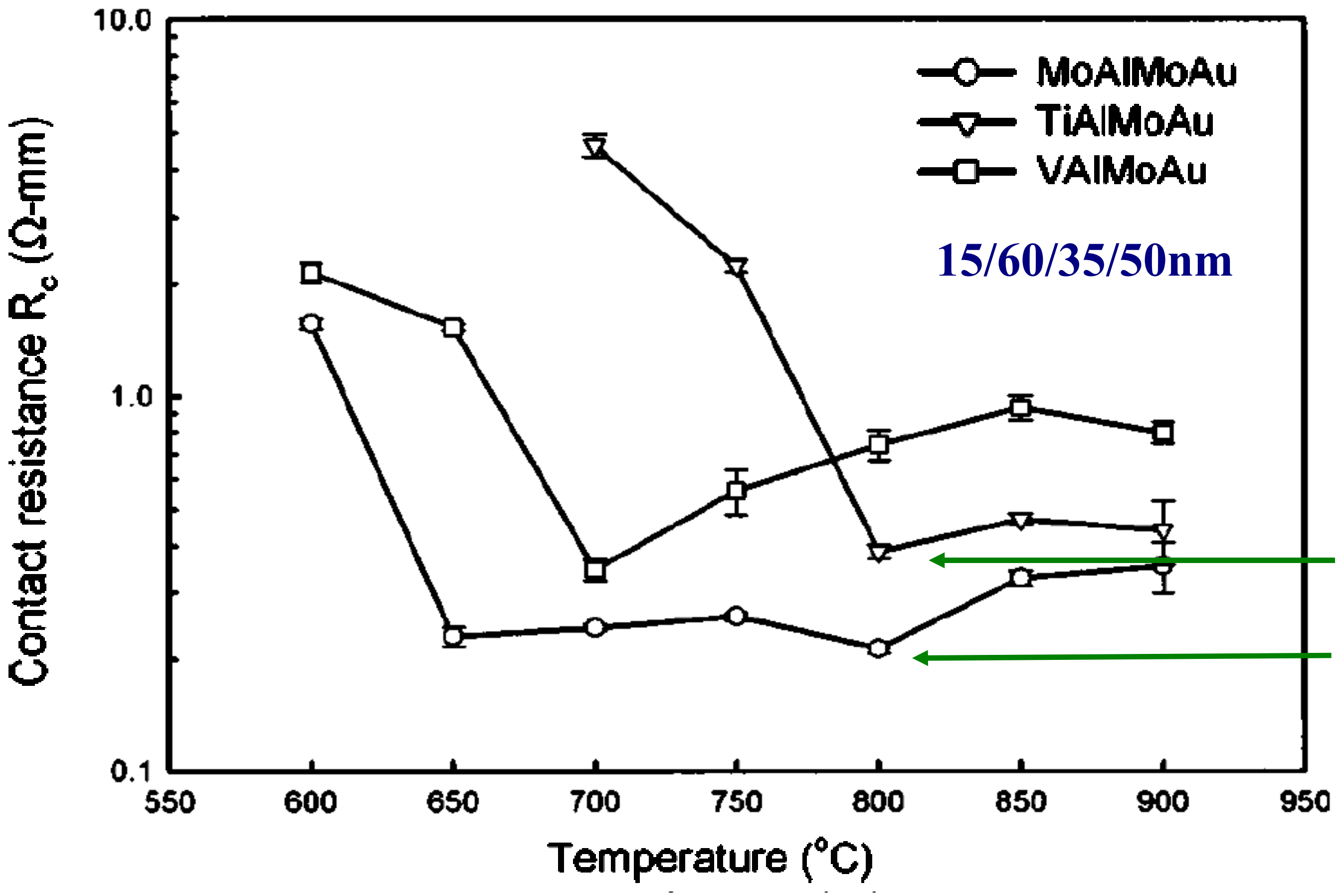
surface defects by damage

surface band bending measured by SP-EFM

RIE : ~200–250 W
100 sccm BCl_3

	As grown	RIE
Control	1.0±0.1 eV	1.4±0.15 eV
Aqua regia	1.1±0.1 eV	1.55±0.15 eV
KOH	1.0±0.1 eV	1.35±0.15 eV

Mo/Al/Mo/Au Ohmic for AlGaN/GaN (I)



15/60/35/50nm

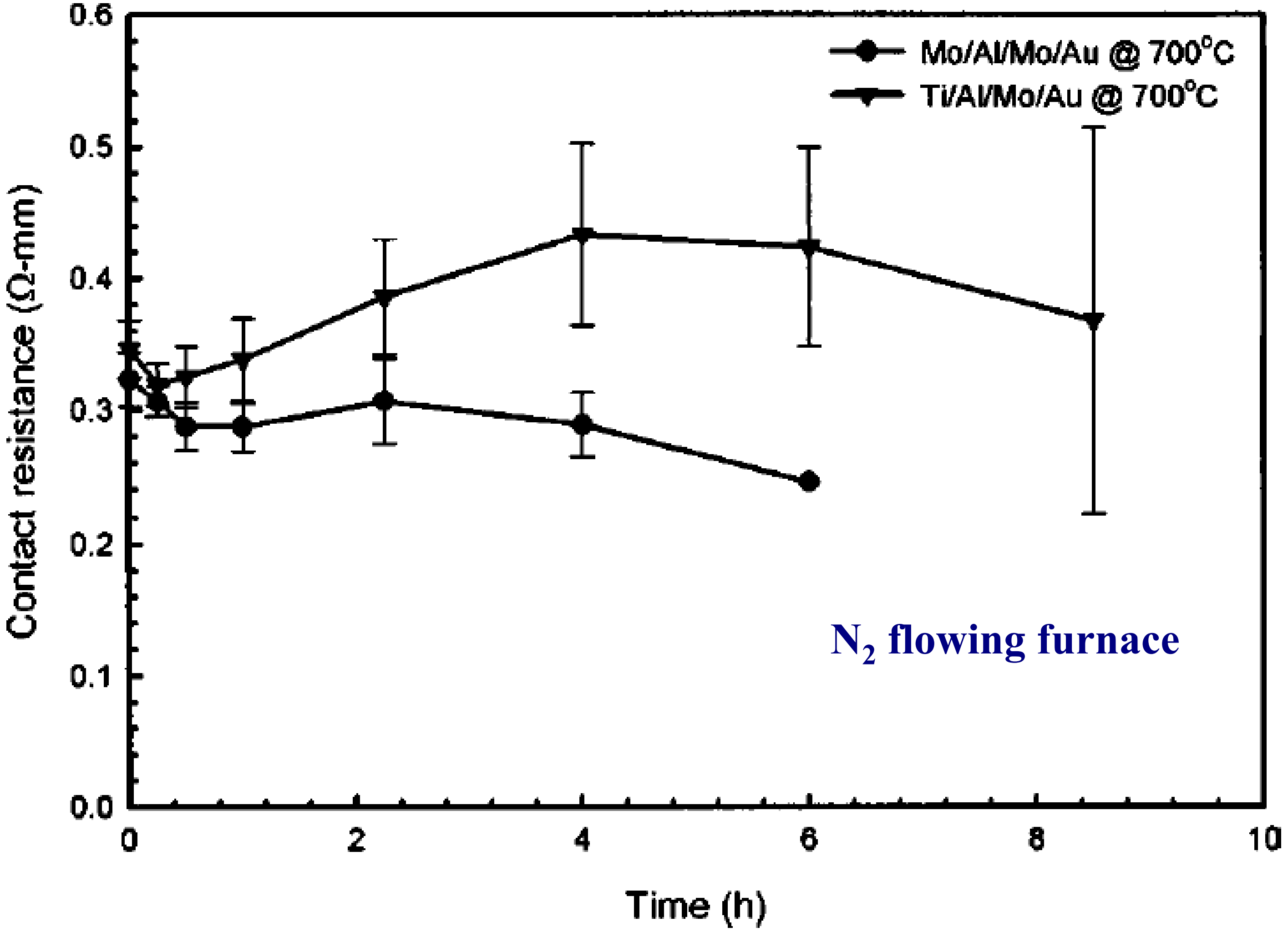
$R_{C.min}$= 0.38 Ω-mm

$R_{C.min}$= 0.22 Ω-mm

- **60s in a $SiCl_4$ RIE** & cleaned in HF prior to metallization
- Annealed under N_2

Ref : D. Selvanathan, et al., JVST B, p. 2409, 2004

Mo/Al/Mo/Au Ohmic for AlGaN/GaN (II)

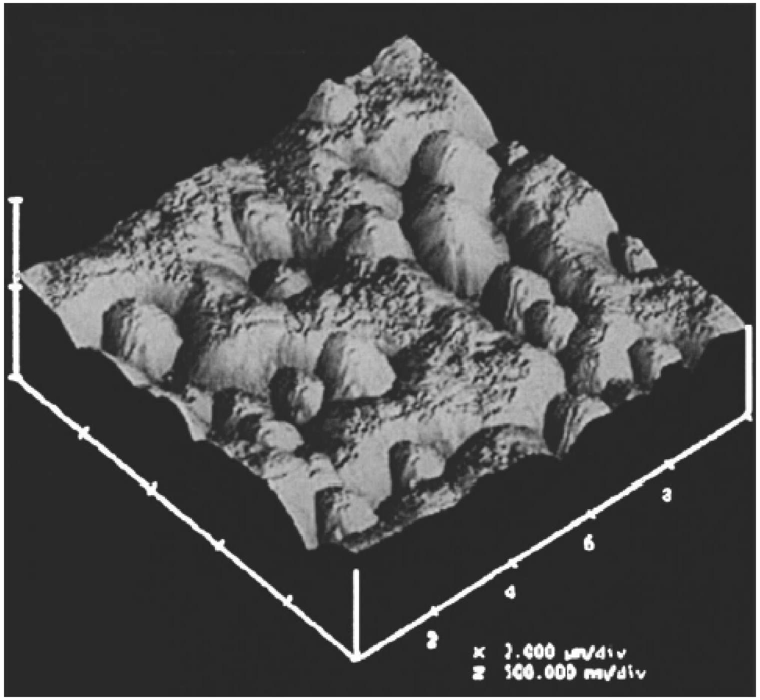


N_2 flowing furnace

Ref : D. Selvanathan, et al., JVST B, p. 2409, 2004

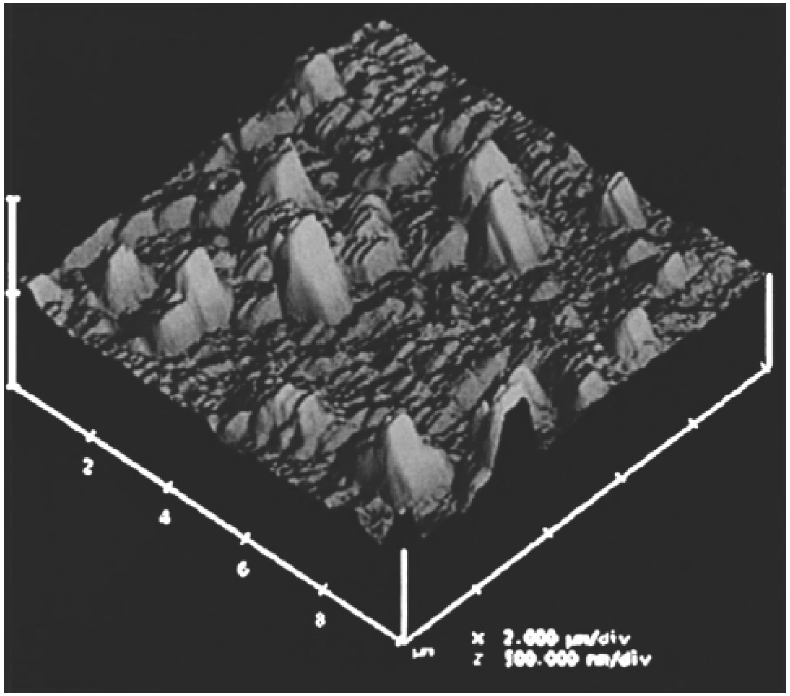
Mo/Al/Mo/Au Ohmic for AlGaN/GaN (III)

Ti/Al/Mo/Au ohmic annealed at 800˚C



rms surface roughness = 48nm

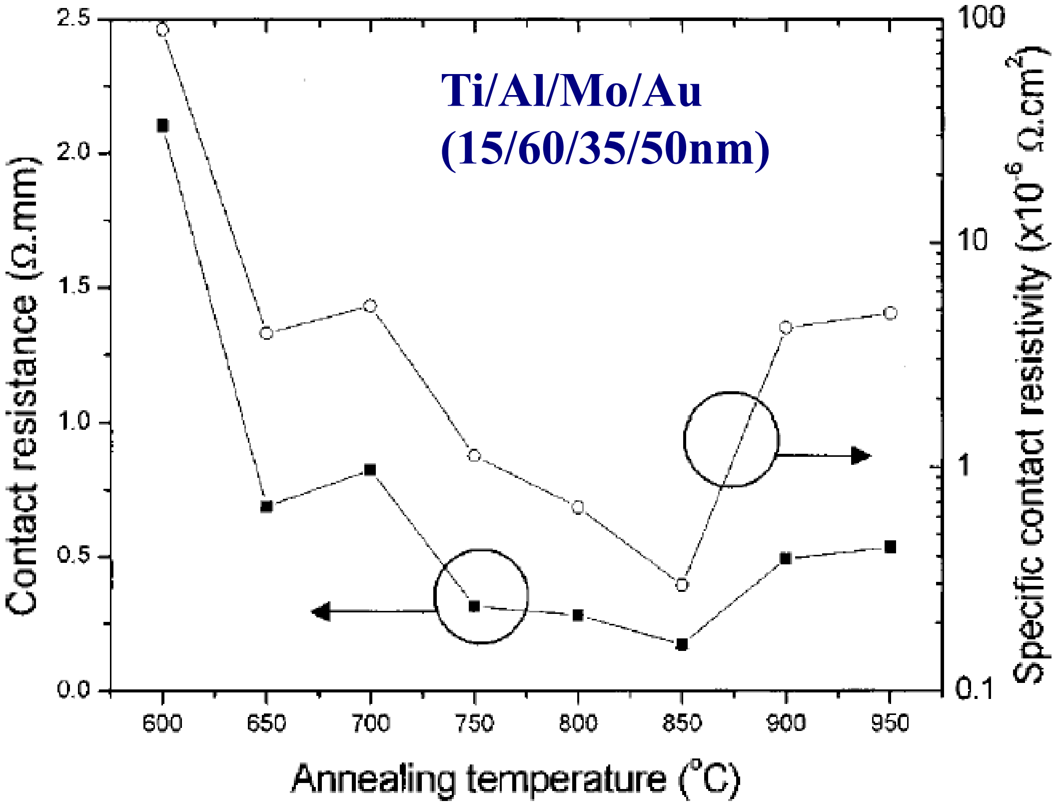
Mo/Al/Mo/Au ohmic annealed at 800˚C



rms surface roughness = 60nm

Ref : D. Selvanathan, et al., JVST B, p. 2409, 2004

Ti/Al/Mo/Au Ohmic for AlGaN/GaN with RIE Treatment



- **60s in a $SiCl_4$ RIE** & cleaned in BOE prior to metallization
- Annealed for 30s under N_2

<AlGaN/GaN with more carriers>

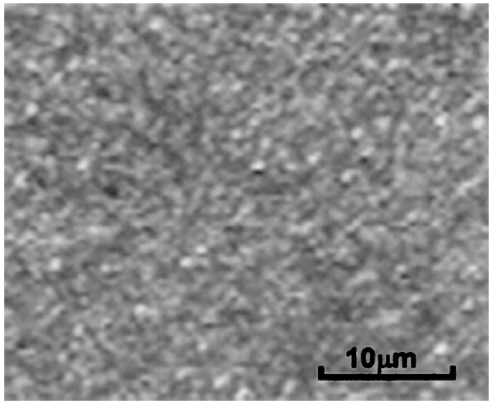
Ti/Al/Mo/Au Contact to AlGaN/GaN

- $\rho_C = 2.9 \times 10^{-7}$ Ω-cm² (0.176 Ω-mm) for 850°C, 30s alloying
- 36 nm RMS roughness after alloying

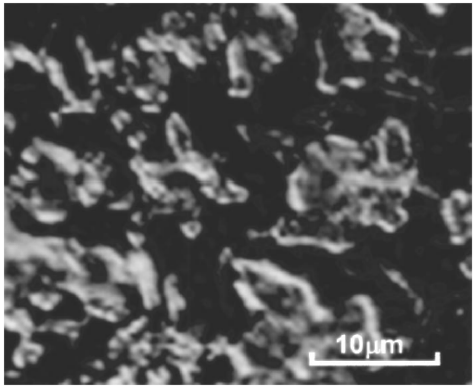
Ref : F. M. Mohammed, et al., JVST B, p. 2330, 2005

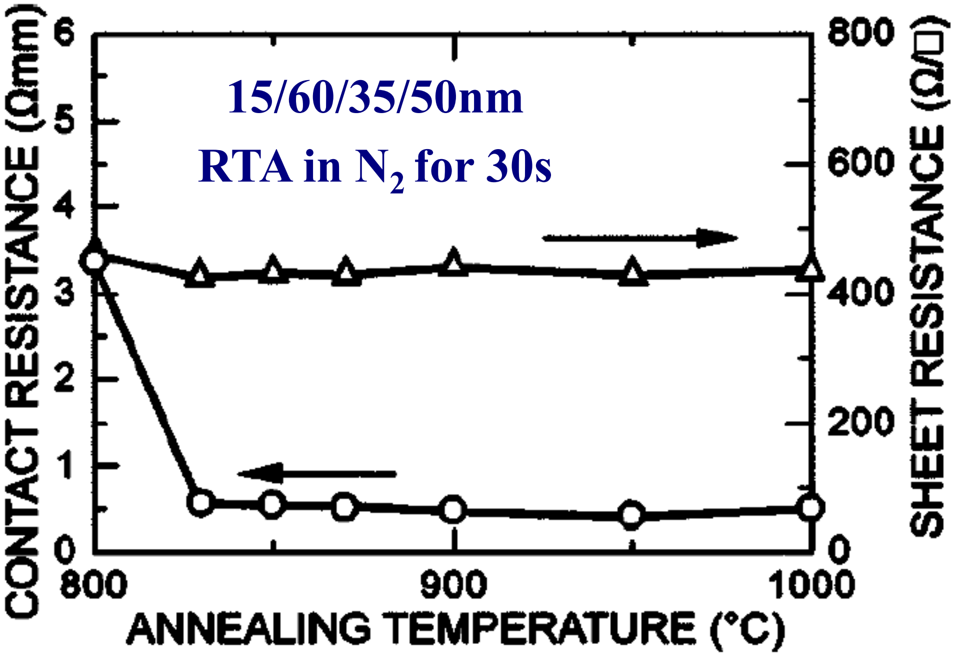
Smooth-Surface Ti/Al/Nb/Au Ohmic for AlGaN/GaN

Ti/Al/Nb/Au Ohmic (900˚C, 30s RTA)
rms roughness – 17nm



Ti/Al/Mo/Au Ohmic (900˚C, 30s RTA)
rms roughness > 100nm





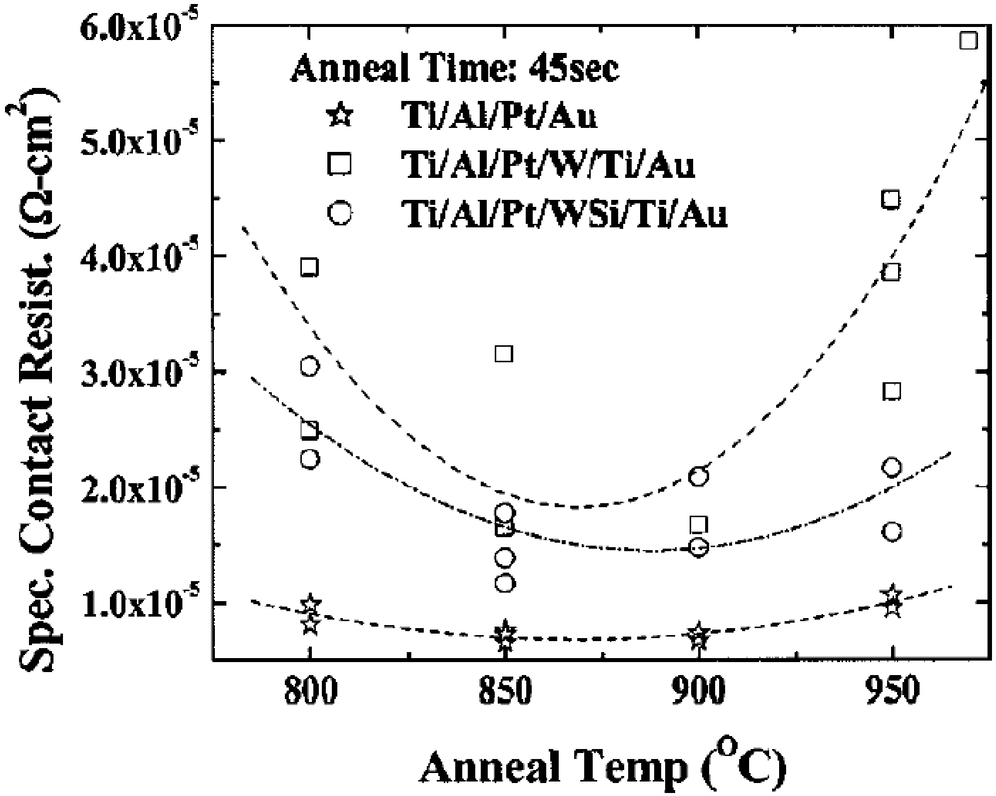
15/60/35/50nm

RTA in N_2 for 30s

850˚C RTA for 100s ⇨ 0.48 Ω/mm
$(5x10^{-6}\ \Omega/\mathrm{cm}^2)$

Ref : T. Nakayama, et al., APL, p. 3775, 2004

Smooth-Surface WSi-based Ohmic for AlGaN/GaN

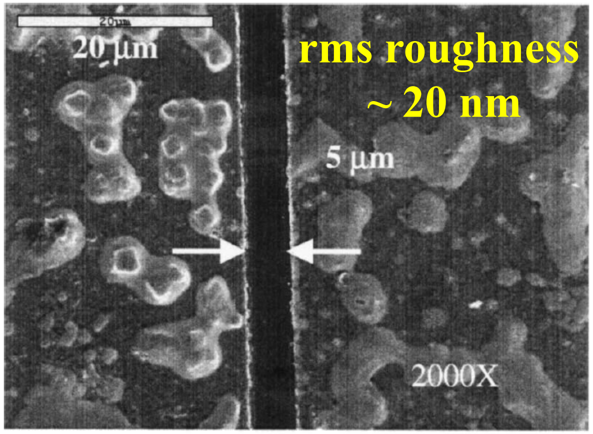


Ti/Al/Pt/WSi$_{0.6}$/Ti/Au (20/100/40/50/20/80nm)

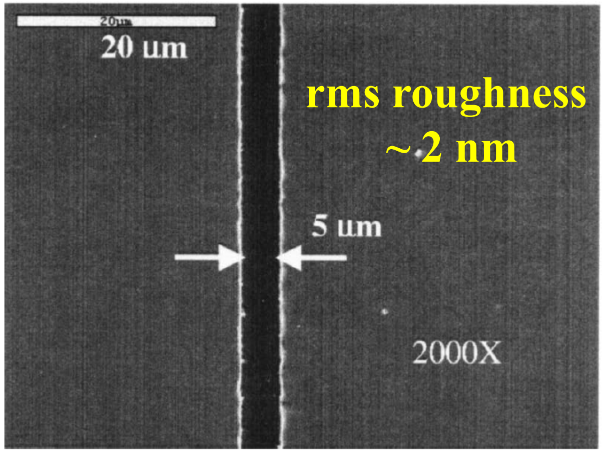
- **WSi$_{0.6}$ – RF Sputtering**
- **BOH etching for remove tungsten oxide**

Ref : B. Luo, et al., APL, p. 3910, 2003

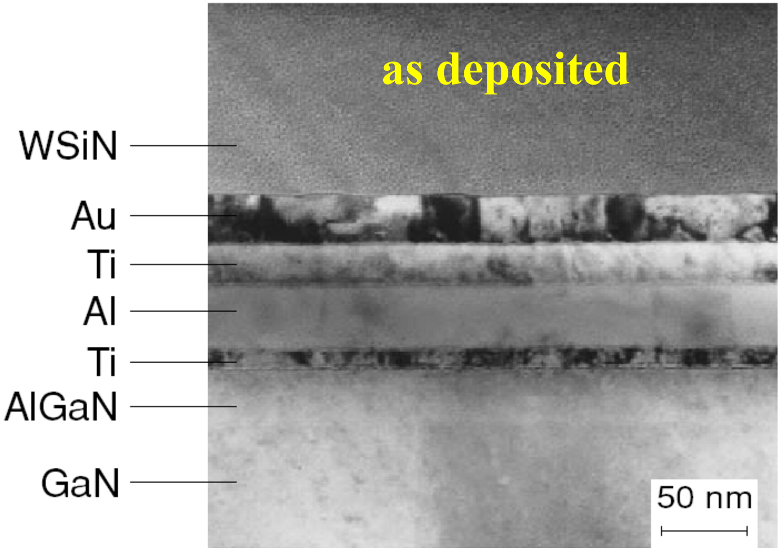
Ti/Al/Pt/Au Ohmic (950°C, 45s RTA)

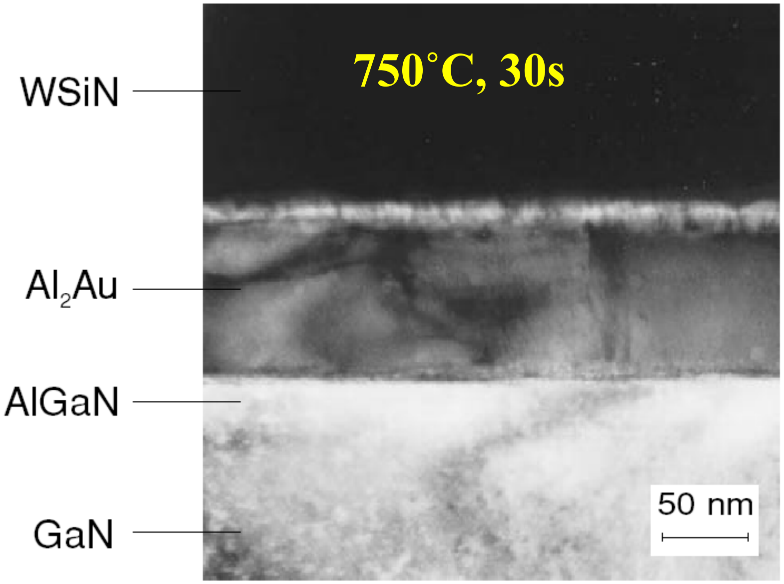


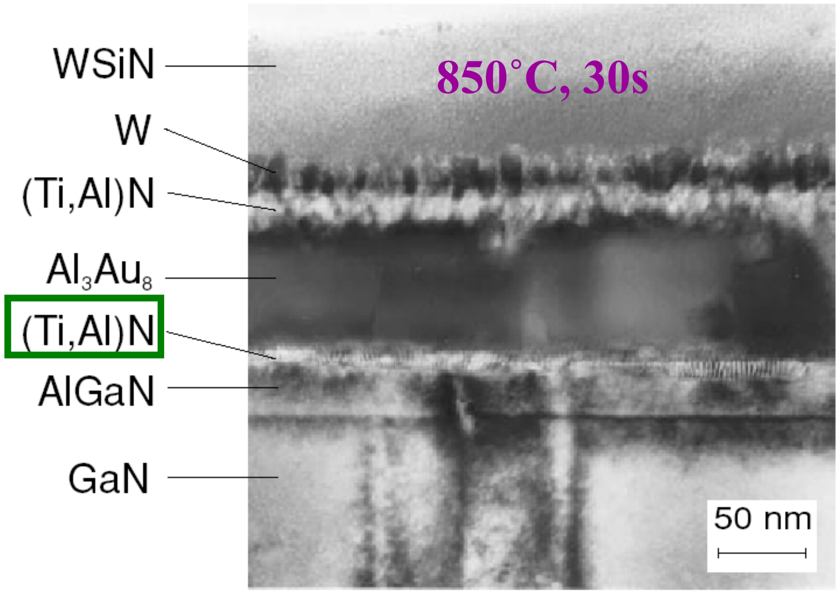
Ti/Al/Pt/WSi/Ti/Au Ohmic (950°C, 45s RTA)



Ti/Al/Ti/Au/WSiN Ohmic Contact to AlGaN/GaN





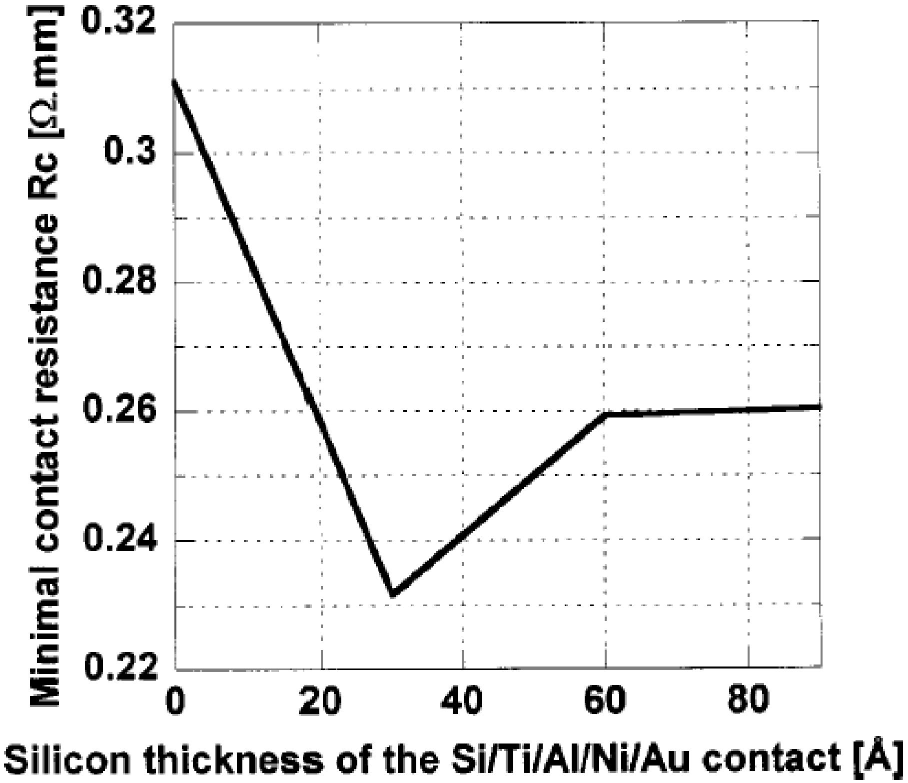


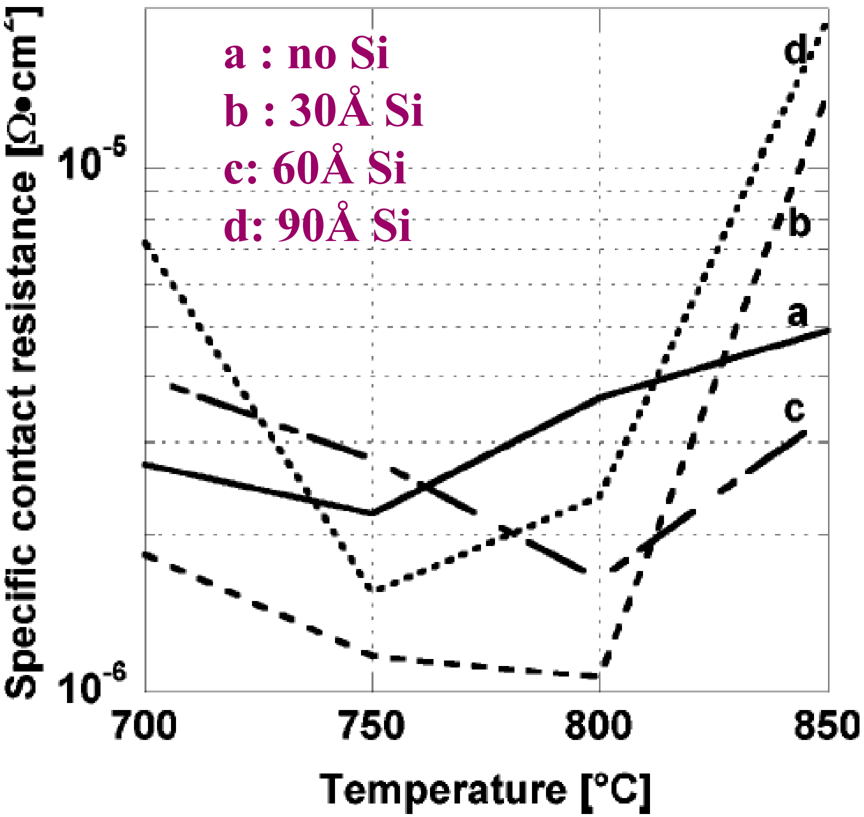
Unreacted WSiN left
– excellent capping

Thermally stable ohmic contact to AlGaN/GaN HEMT structure
⇨ 0.77Ω-mm after 400°C, 24hr aging

Ref : E Nebauer, et al., Semicond. Sci. Technol. p. 249, 2002

Low-Resistance Si/Ti/Al/Ni/Au Ohmic for AlGaN/GaN





Si(30Å)/Ti/Al/Ni/Au (30s at 800°C) ⇨ 0.23Ω-mm, 1.06x10^{-6} Ω-cm^2

(* All layers are e-gun evaporated.)

Ref : V. Desmaris, et al., Electrochemical and Solid-State Letters, p. G72, 2004