PROCESSING TECHNOLOGIES FOR $Al_xGa_{1-x}N$ OPTOELECTRONIC DEVICES

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Research Areas

- Ohmic contacts for n- and p-type GaN and AlGaN materials.
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2. Schottky metallization on AlGaN

3. Photoelectrochemical etching (PEC)

4. Dry Etching of AlGaN by ICP-RIE

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Background

Challenges in achieving good *p*-GaN ohmic contacts:

•Low solubility of Mg and large acceptor binding energy

•Wide bandgap of GaN: $\phi_b = (\chi_s + E_g) - \phi_m$

⇒ large barrier height of 1.8 eV even with Pt contacts

Solutions:

•Surface modification:

⇒ reduce contamination, restore stoichiometry.

⇒ Create highly doped near-surface layer through etching.

•Band engineering:

⇒ Superlattice doping (GaN/AlGaN-SL, GaN/InGaN-SL).

•Combination of above.

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Motivation

- Compare "2-step" surface treated samples (ultrasonic surface clean in BOE prior to patterning, then BOE clean again before metal evaporation) to Ti-based metallizations.
- Study dopant activation energy in $GaN/Al_xGa_{1-x}N$ superlattices (x = 0.1 and 0.2)
- Study stability of Ti/Pt/Au contacts.

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Sample Cross-sections

Au > 80 nm
Pt: 50~80 nm
Ti : 3~25 nm
p-GaN ~ 0.3 μm
i-GaN ~ 3 μm
Sapphire

	Au > 80 nm
	Pt : 50~80 nm
	Ti : 3~15 nm
20x	*p*-$Al_xGa_{1-x}N$ ~ 10 nm
	p-GaN ~ 10 nm
	Sapphire

p-GaN substrates:

- MOCVD-grown
- $N_A \sim 3 \times 10^{17}$ cm^{-3}
- Mobility: ~9 $cm^2V^{-1}s^{-1}$

Superlattice substrates:

- MBE-grown
- $N_A \sim 10^{19}$ cm^{-3}
- Mobility: ~1 $cm^2V^{-1}s^{-1}$

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Processing Steps

For Ti/Pt/Au:

- Mesa isolation using ICP-RIE,
- Surface preparation: solvent only,
- Pattern TLM pads,
- Oxygen plasma descum,
- Surface cleaning using HCl:DI
- Metal deposition,
- RTA at 1 atm flowing N_2.

"2-Step" cleaning for other metals:

- Mesa isolation using ICP-RIE,
- Surface preparation: solvent+BOE,
- Pattern TLM pads,
- Oxygen plasma descum,
- Surface cleaning using BOE.
- Metal deposition,
- RTA at 1 atm flowing N_2.

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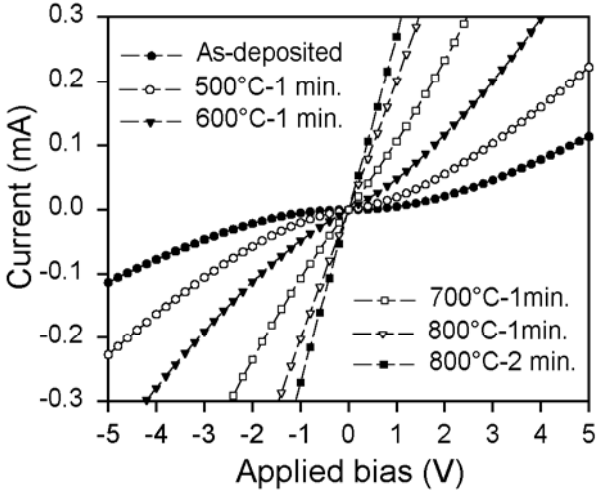
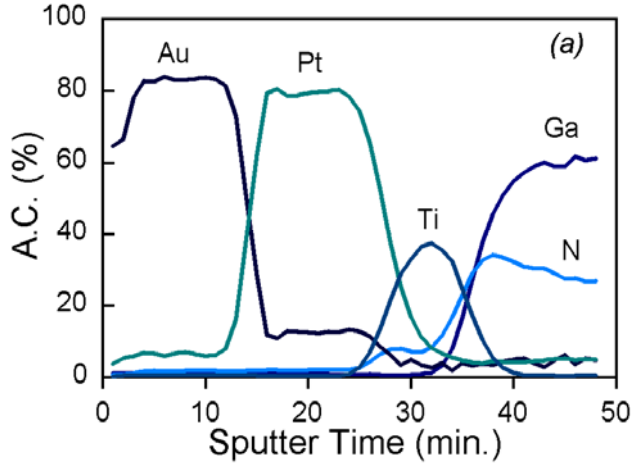
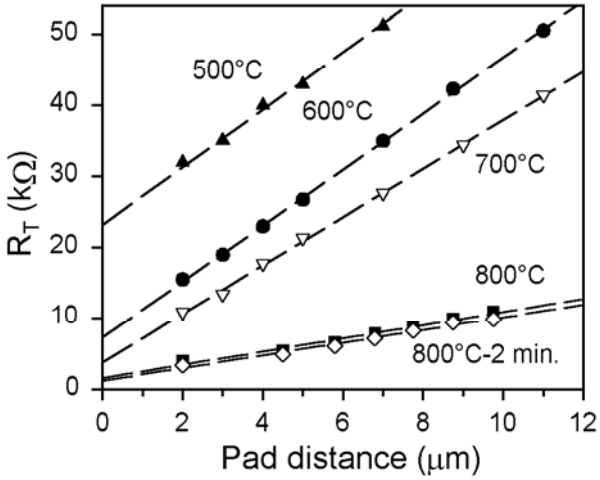
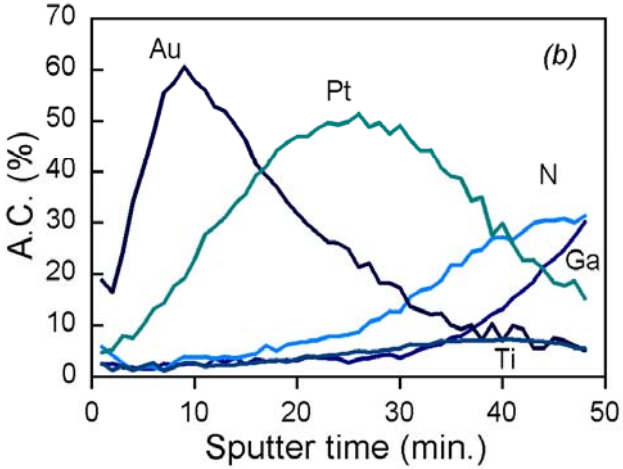
Ti/Pt/Au contacts on p-type GaN









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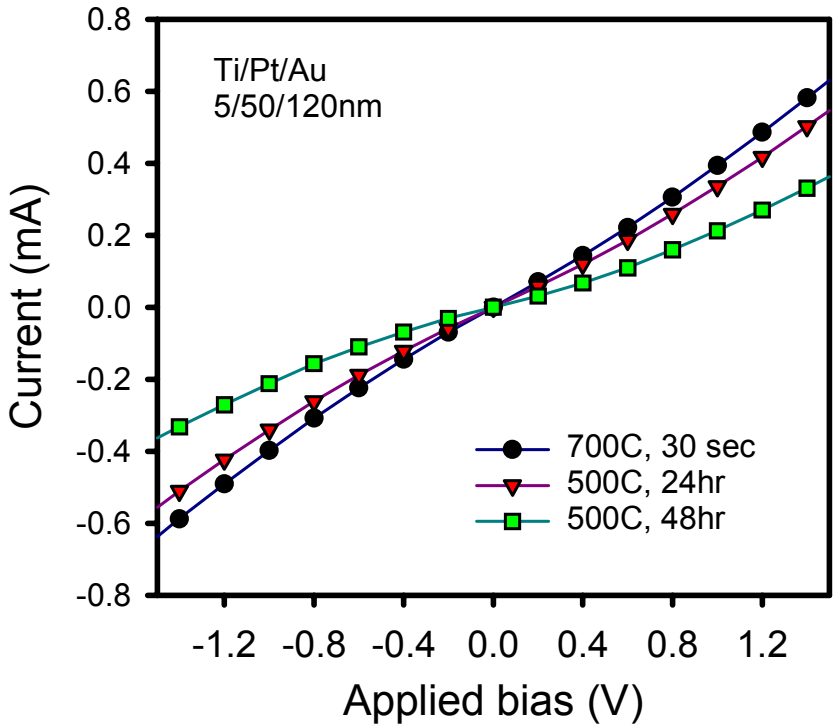
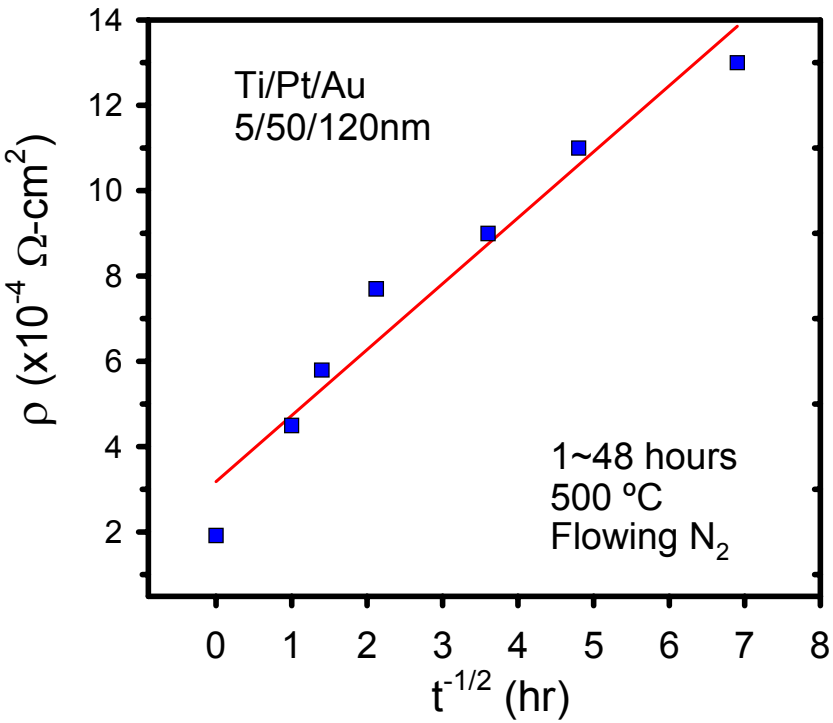
Temperature Stability of Ti/Pt/Au Contacts on p-type GaN





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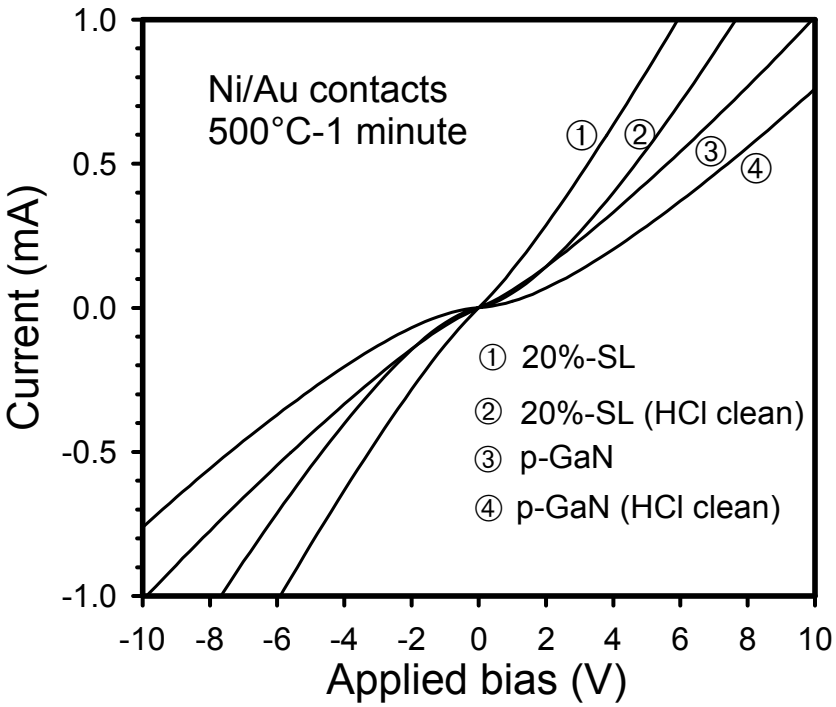
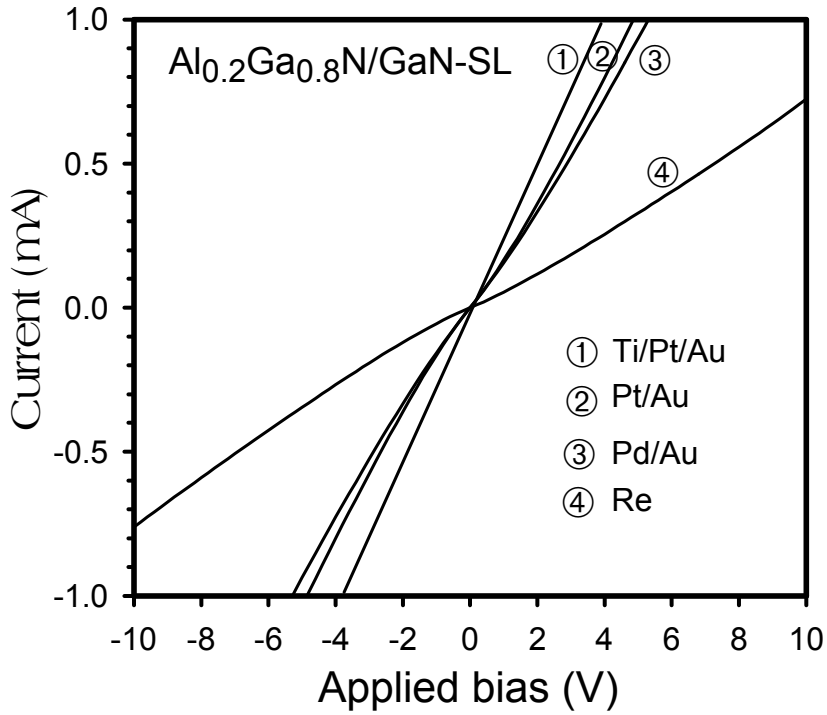
I-V Characteristics of Ohmic Contacts on GaN/AlGaN-SL





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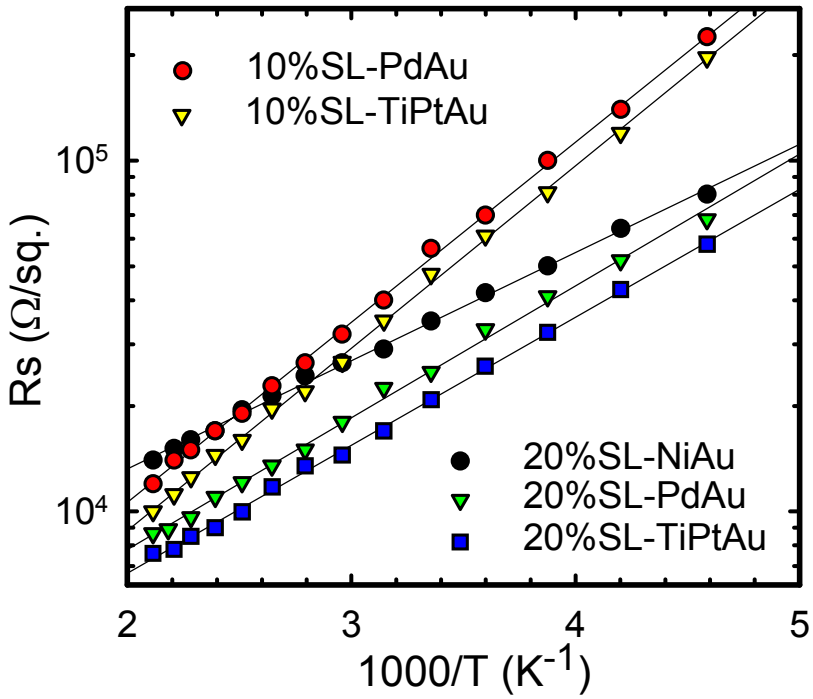
Dependence of Sheet Resistance on Temperature



$R_{sh} \propto \rho/t$
$=1/(\sigma t)$
$\sigma = q\mu_h p$

Temperature range:
-55~200 °C
$E_{a(x=0.1)} \approx 90$ meV
$E_{a(x=0.2)} \approx 60$ meV

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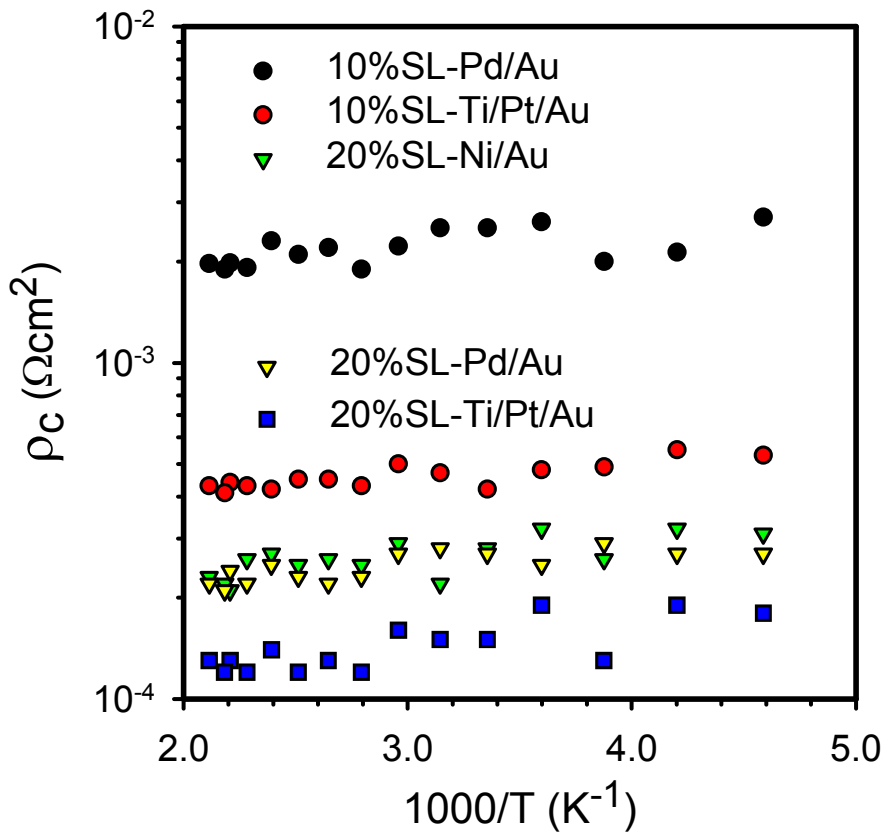
Dependence of Contact Resistance on Temperature



$$E_{00} = \frac{qh}{4\pi}\sqrt{\frac{N_a}{m_h \varepsilon_s}}$$

$$= 1.85\times10^{-11}\left[\frac{N_a}{(m_h/m_0)(\varepsilon_s/\varepsilon_0)}\right]$$

$$\approx 1.85\times10^{-11}\left[\frac{N_a}{(A^{**}/120\alpha)(\varepsilon_s/\varepsilon_0)}\right]$$

$N_a \sim 4\times10^{18}\ cm^{-3}$

$A^{**} \sim 1\%$ theoretical value

$E_{00}/kT >> 1$

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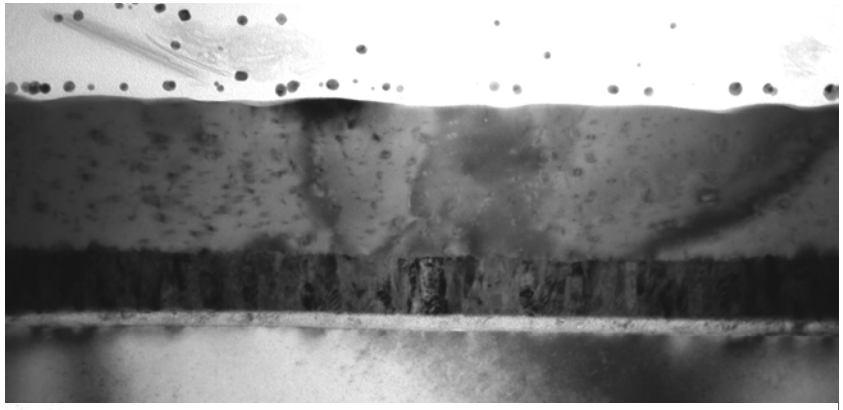
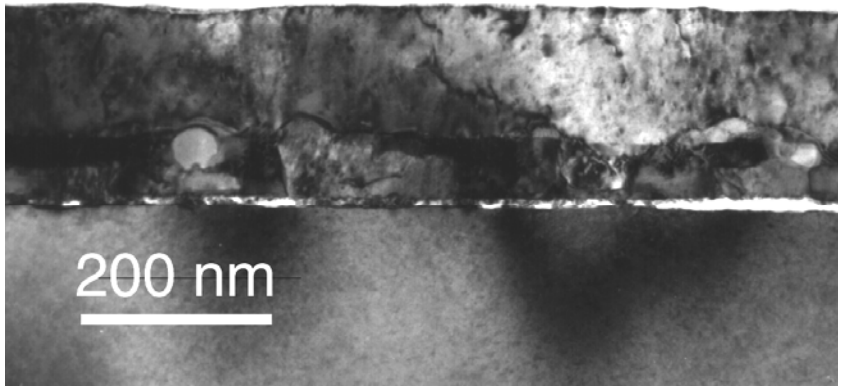
Contact Degradation Above 800 °C



As-deposited



Annealed at 800 °C
for 10 minutes

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Summary of Results for Ti/Pt/Au

Material	Contact Resistivity (Ω-mm)			Specific Contact Resistance (Ω-cm^2)		
	As-dep	300°C	800°C	As-dep	300°C	800°C
p-GaN (p=3E17)	Schottky	~200	21	Schottky	$6x10^{-2}$	$4.2x10^{-5}$
10%SL	72	62	Schottky	$6.6x10^{-4}$	$4.7x10^{-4}$	Schottky
20%SL	41	24	Schottky	$4.6x10^{-4}$	$1.3x10^{-4}$	Schottky
n-GaN (n=4E18)	Schottky	ohmic	Schottky	Schottky	ohmic	Schottky

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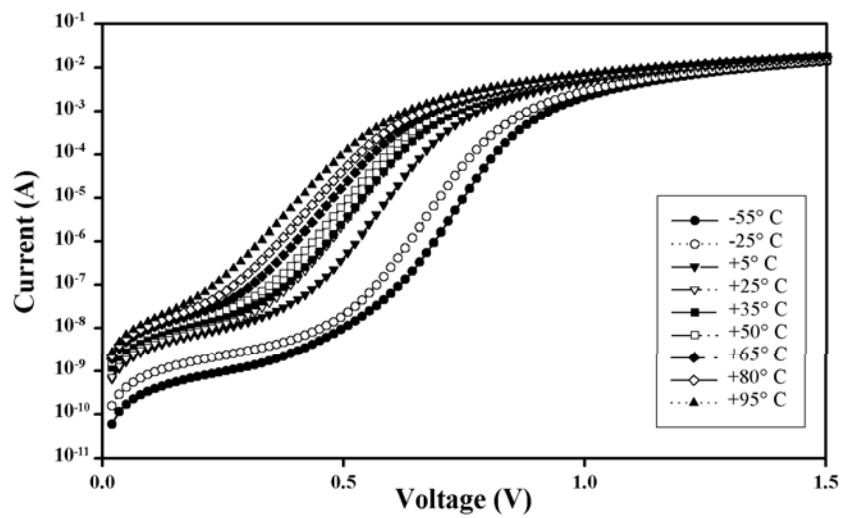
Characterization of Schottky Contacts on *n*- $Al_xGa_{1-x}N$



Plot of the I-V-T data for a Au contact on $Al_{0.2}Ga_{0.8}N$.
I-V-T data for temperatures +25 °C → +95 °C were used for modified Norde plot analysis. The same procedure was repeated for all eight metals on 4 compositions of AlGaN.

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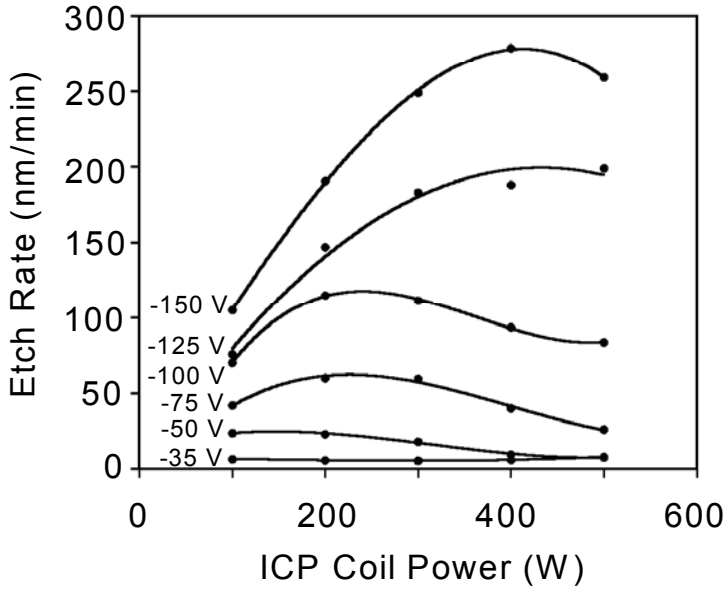
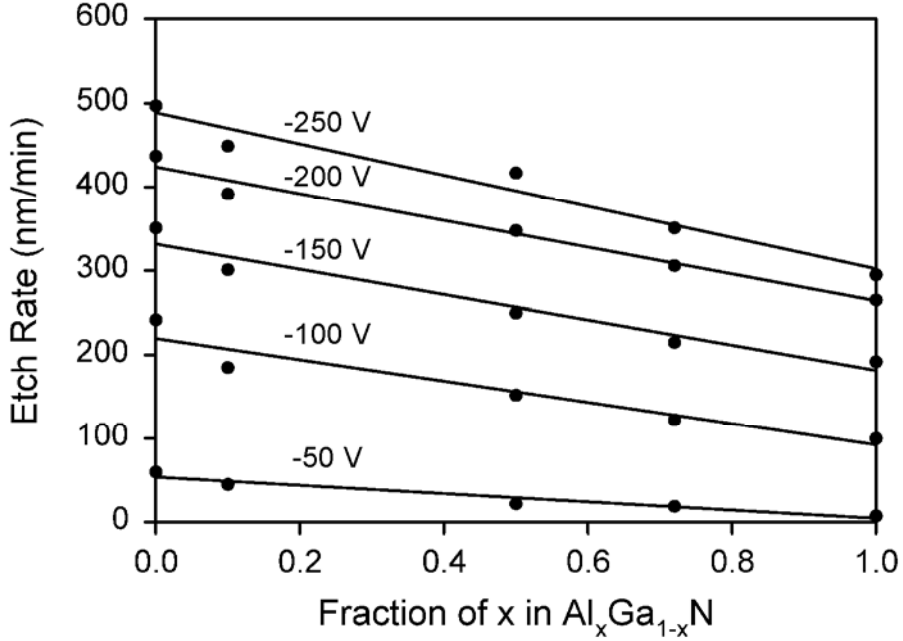
Etch Rate Curves for $Al_xGa_{1-x}N$



Etch rate vs. ICP coil power (Chamber pressure = 3 mT; Cl2/Ar gas flow rate = 14/6 sccm)



ICP coil power = 500W; pressure = 5mT; Cl_2/Ar gas flow rate = 25/5 sccm.

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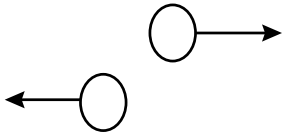
Plasma-Induced Damage

$Al_{0.25}Ga_{0.75}N$	100Å	undoped
$Al_{0.25}Ga_{0.75}N$	200Å	undoped
$Al_{0.25}Ga_{0.75}N$	30Å	undoped
GaN	2μm	undoped
Sapphire		

HEMT structure



Normalized mobility and Sheet concentration vs. Etch Duration (ICP coil power = 300 W; Bias voltage = -100 V; Chamber pressure = 3 mT; Ar gas flow rate = 20 sccm)

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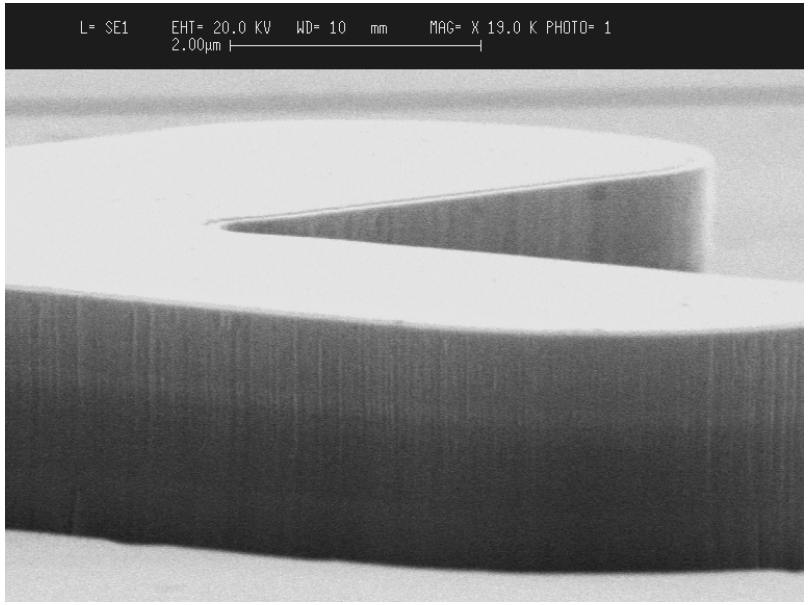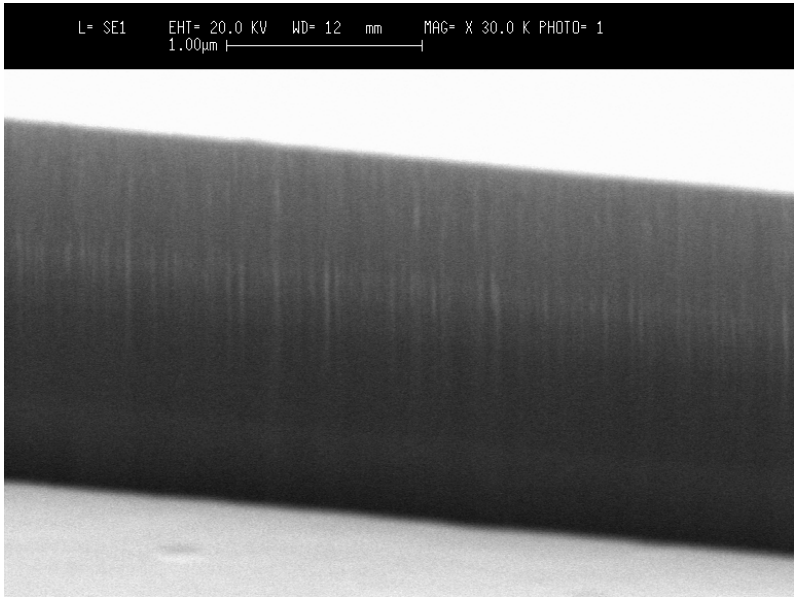
ICP-RIE Etched Laser Facet