GaN-based Robust Micro Pressure and Temperature Sensors for Extreme Planetary Environments

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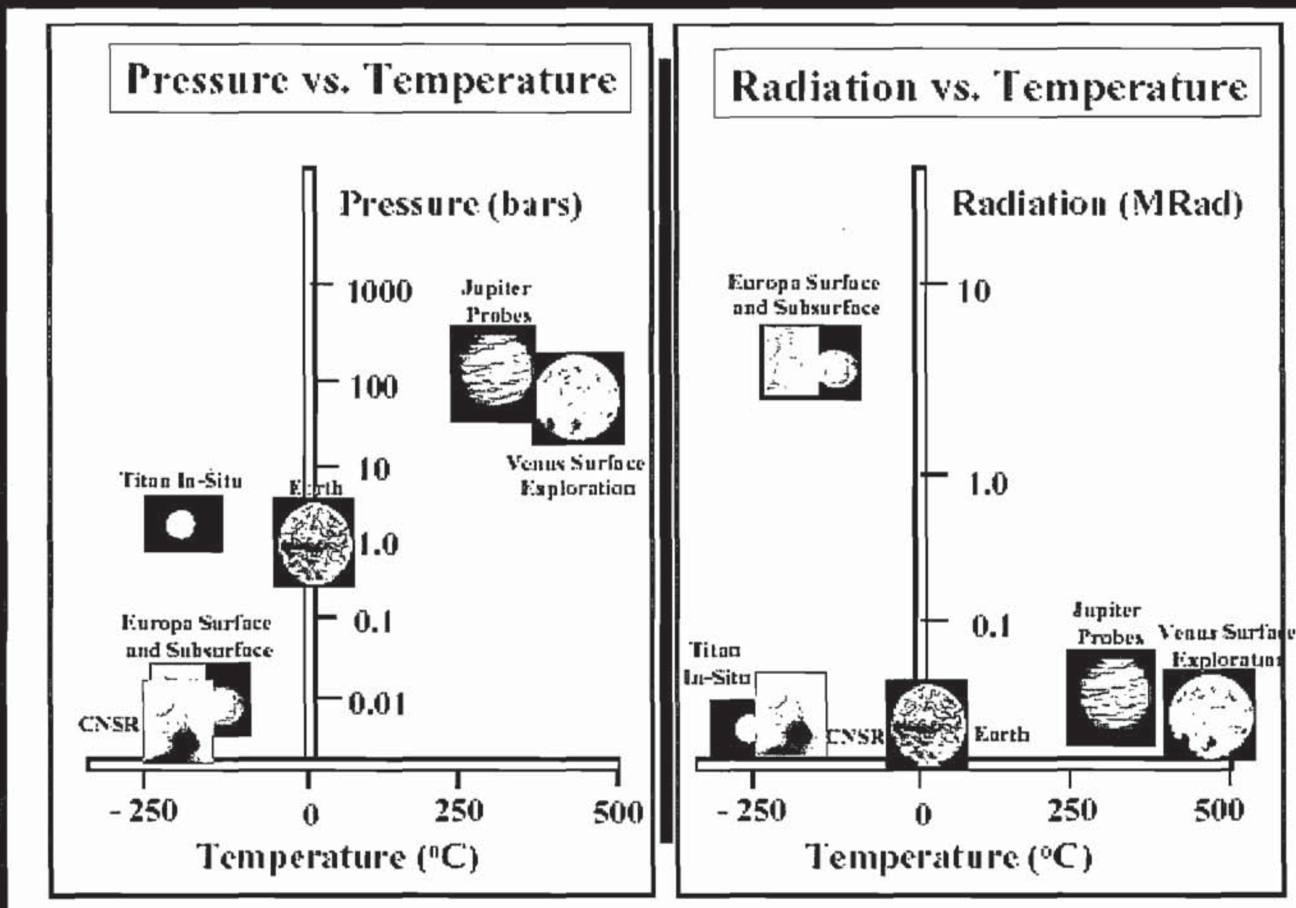
Temperature, Pressure, and Radiation in Reference Missions



Chris Moore, "Technology Development for Extreme Environments Systems" Workshop on Extreme Environments Technologies for Space Explorations, Pasadena, May 14, 2003.

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Extreme Environments in Five Space Science Reference Missions

All five missions have to survive in extreme environments.

Mission	Low Temp.	High Temp.	High Rad.	High P.
Venus Surface Exploration & sample return		460 C		90 bar
Giant Planets Deep Probes	-140 C	380 C		100 bar
Comets Nucleus Sample Return	-140 C			
Titan *In Situ*	-180 C			
Europa Surface & Subsurface	-160 C		5 MRad	

Chris Moore, "Technology Development for Extreme Environments Systems"
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AlGaN/GaN Hetero Structure-based Micro Sensors

Merits:

- Superior materials properties; Ideal for extreme environments

Mechanically strong, chemically & thermally inert, radiation hard
Minimal in unwanted optical or thermal generation of charge carriers

- Small volume, low mass, and low power requirement
- Novel device concept and simple & reproducible fabrication
- Monolithic integration to GaN-based RF transceiver

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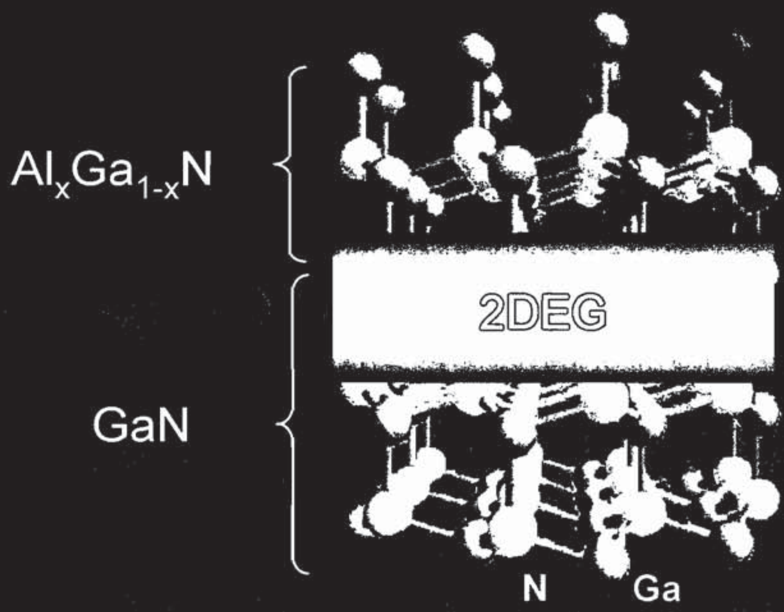
AlGaN/GaN Heterostructure Devices for Pressure Sensing



- Sheet charge layer (2-Dimensional Electron Gas) at the interface of GaN and AlGaN

- Applied stress/pressure

⇩

Modulation of the electron concentration & the conduction in the 2DEG.

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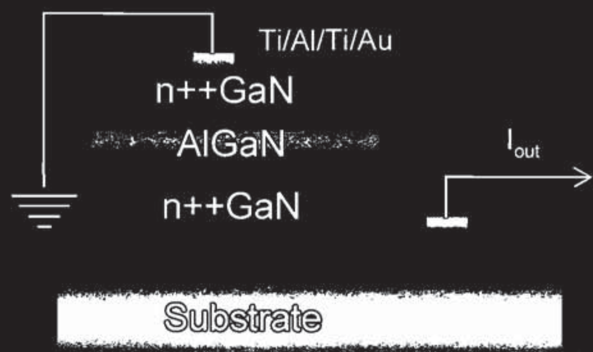
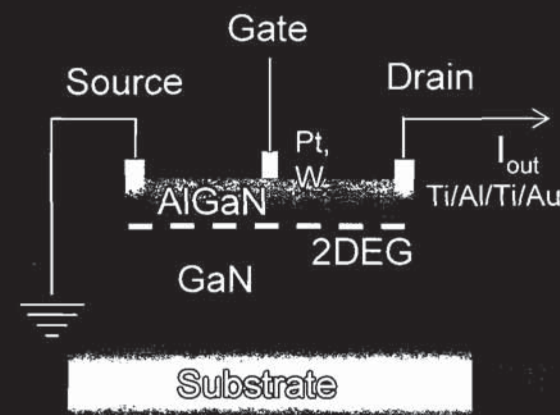
AlGaN/GaN based High Pressure Sensors



Schematic cross section of **n-GaN/AlGaN/n-GaN (n-I-n)** vertical transport diode sensor



Schematic cross section of **AlGaN/GaN HEMT** sensor

Expected operational range:
- 0-10 kbar with 1 mbar accuracy
- 30 K - 870 K with 0.1 K accuracy

Expected volume: ~ 1 cm^3
- mass: < 5 g
- power requirement: < 10 mW

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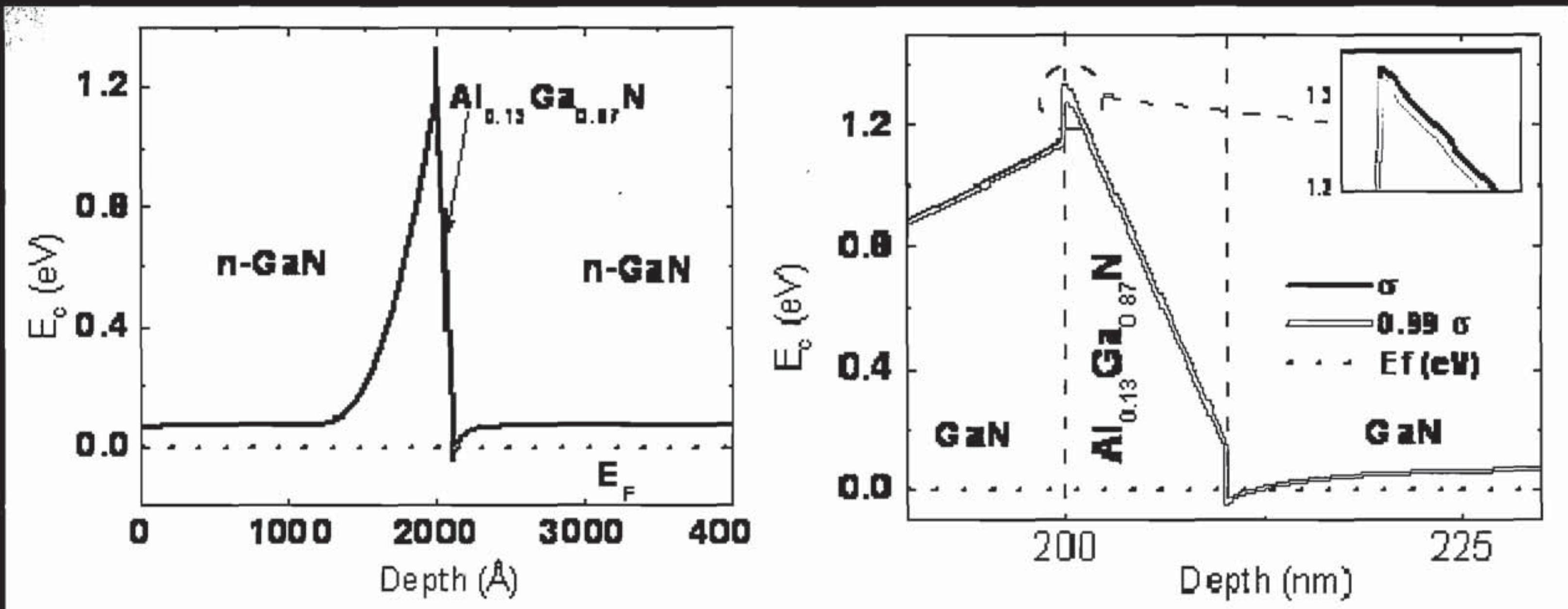
Conduction Band Diagram of $GaN/Al_xGa_{1-x}N/GaN$ sensor



Conduction band diagram of $n\text{-}GaN/Al_{0.13}Ga_{0.87}N/n\text{-}GaN$

- for 10 nm thick undoped $Al_{0.13}Ga_{0.87}N$ and 2×10^{17} cm^{-3} doping in both n-GaN regions
- estimated polarization charge at the $Al_{0.13}Ga_{0.87}N$/n-GaN: 7.24 $\times10^{12}$ ecm^{-2}
- calculated barrier height:1.33 eV
- **12 meV decrease of barrier height expected from 1% reduction of polarization charge; 60 % increase in thermionic emission current over the barrier.**

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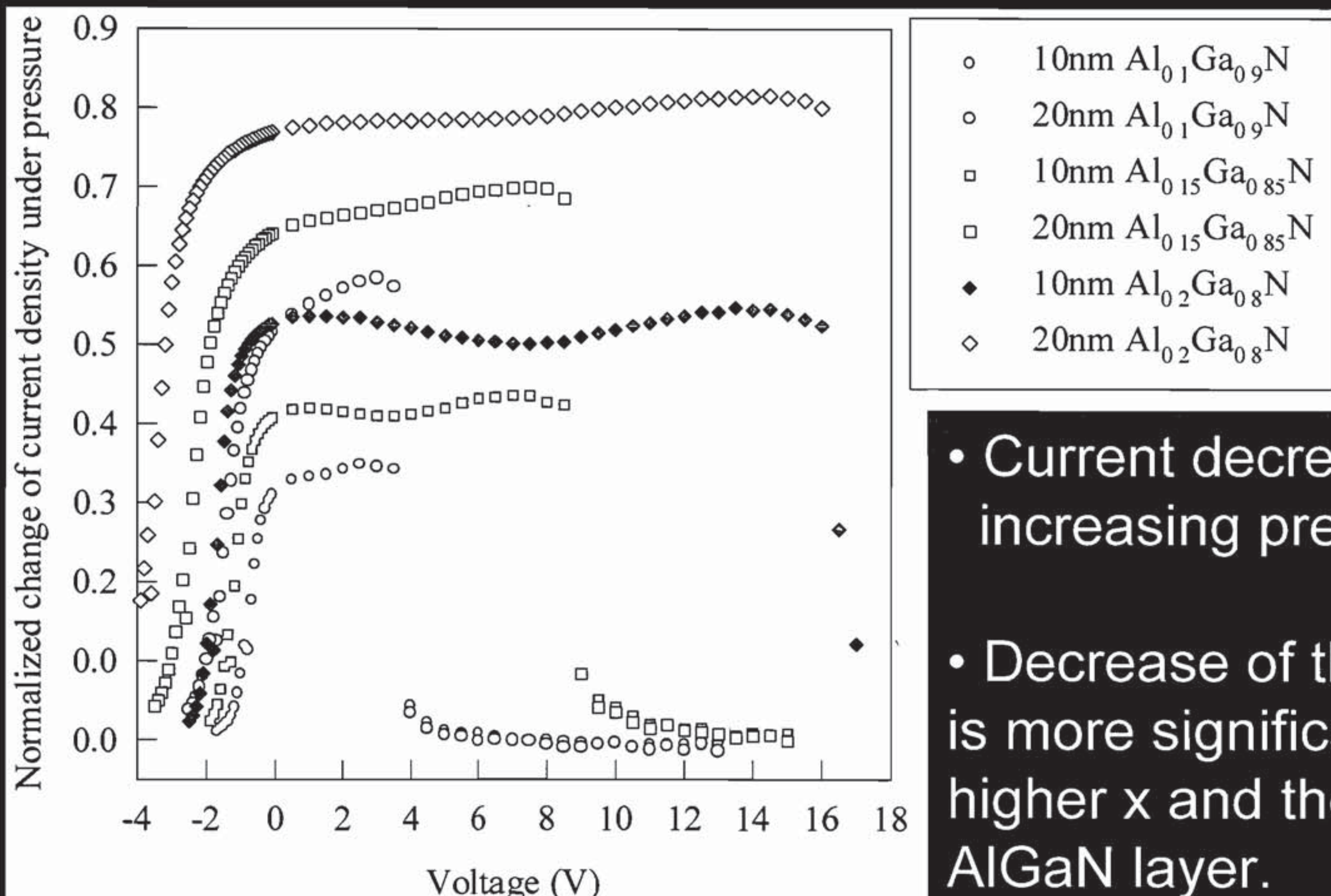
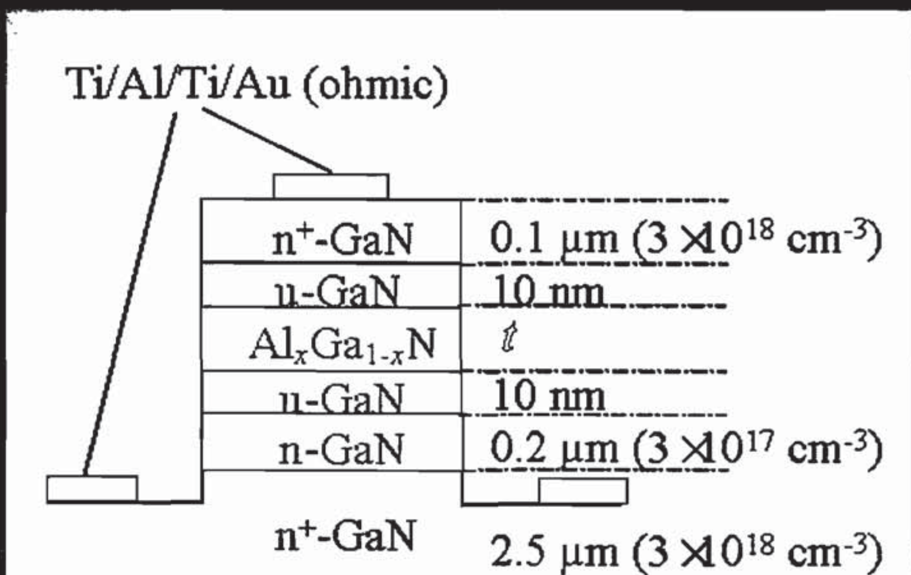
Theoretical Modeling of Pressure Effect on n-I-n Sensor

Normalized change of current densities, $(J_0-J)/J_0$, calculated for $GaN/Al_xGa_{1-x}N/GaN$ heterojunction under 10kbar hydrostatic pressure



- Current decreases with increasing pressure.
- Decrease of the current is more significant with higher x and the thicker AlGaN layer.

GaN/Al$_x$Ga$_{1-x}$N/GaN (n-I-n) Sensor Structure



Al$_x$Ga$_{1-x}$N thickness: t

AlN % \ t (nm)	10nm	20nm	30nm
12%		CVD1210	
15%	CVD1209	CVD1208	CVD1211
30%		CVD1205	

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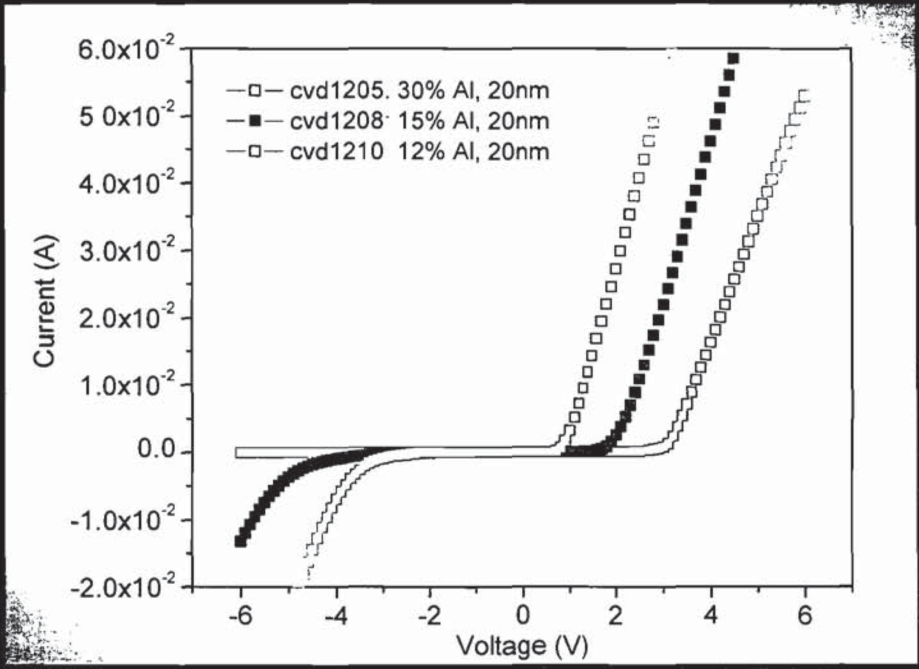
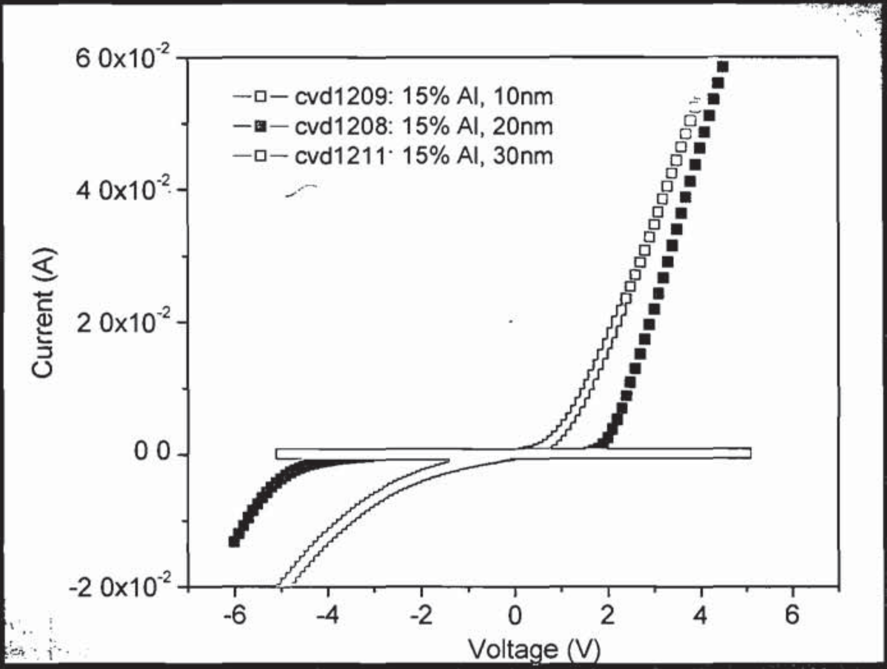
I-V Characteristics of n-I-n Sensors

Different Al compositions in $Al_xGa_{1-x}N$



Different thicknesses of $Al_xGa_{1-x}N$



Higher turn-on voltage with higher Al content and thicker $Al_xGa_{1-x}N$

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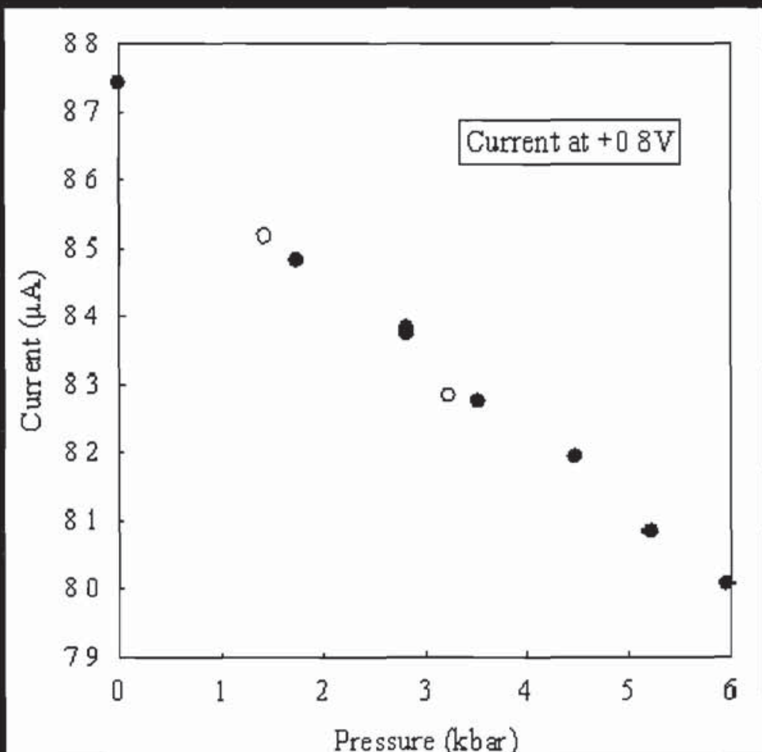
Electrical Responses of n-I-n Sensor to Hydrostatic pressure

Pressure response measured for the n-GaN/$Al_{0.15}Ga_{0.85}N$ /n-GaN



Current was measured under hydrostatic pressure at a fixed forward bias (+0.8 V) while the pressure was increased (solid dots) and decreased (open dots) as well.

- Linear decrease of current with increasing pressure
- Reversible response

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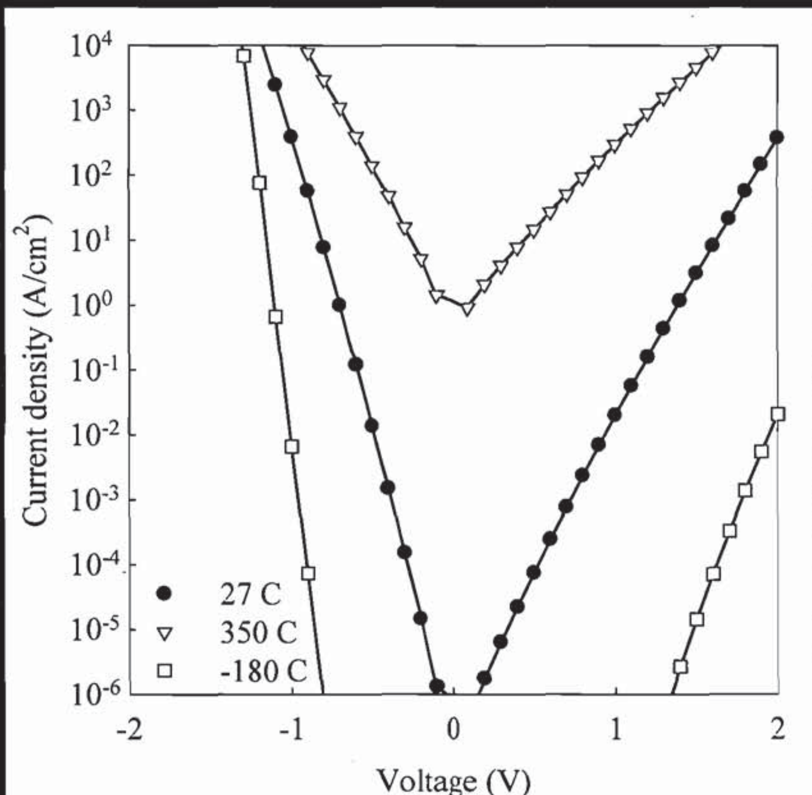
Theoretical Modeling of Temperature Responses of n-I-n Sensor

Current density vs. voltage plots for $GaN/Al_{0.15}Ga_{0.85}N/GaN$ sensor at zero pressure



Calculated with doping density of 3×10^{18} cm^{-3} for top GaN layer and 3×10^{17} cm^{-3} for bottom GaN layer. 10 nm thick undoped AlGaN layer is assumed.

Current decreases strongly with decreasing temperature.

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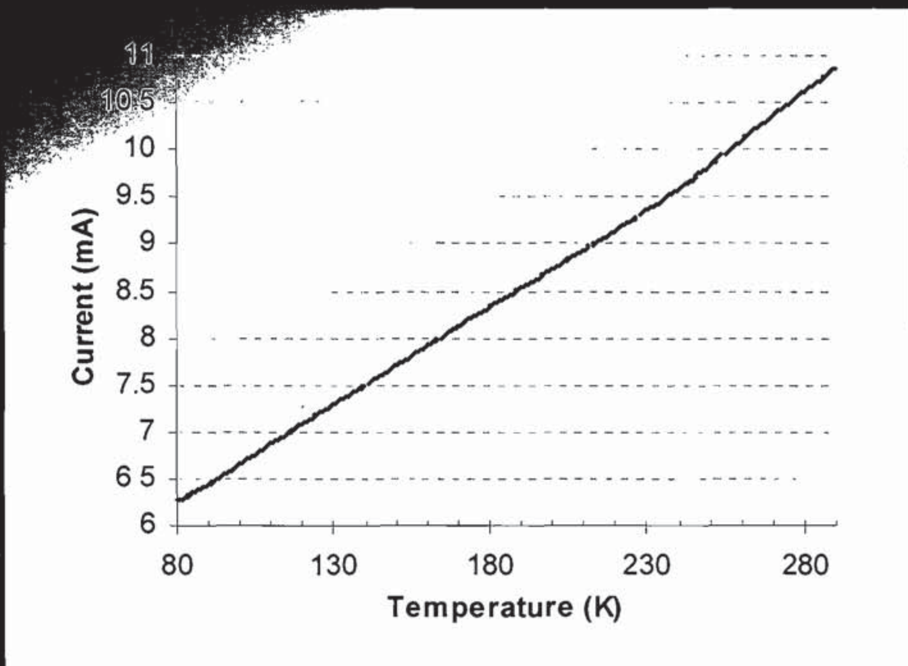
Temperature response of n-I-n sensor

Temperature response of $GaN/Al_{0.15}Ga_{0.85}N/GaN$ sensor



20 nm-thick $Al_{0.15}Ga_{0.85}N$ layer
The current was measured with a forward bias of 1.5 V.

- Good linearity between current and temperature

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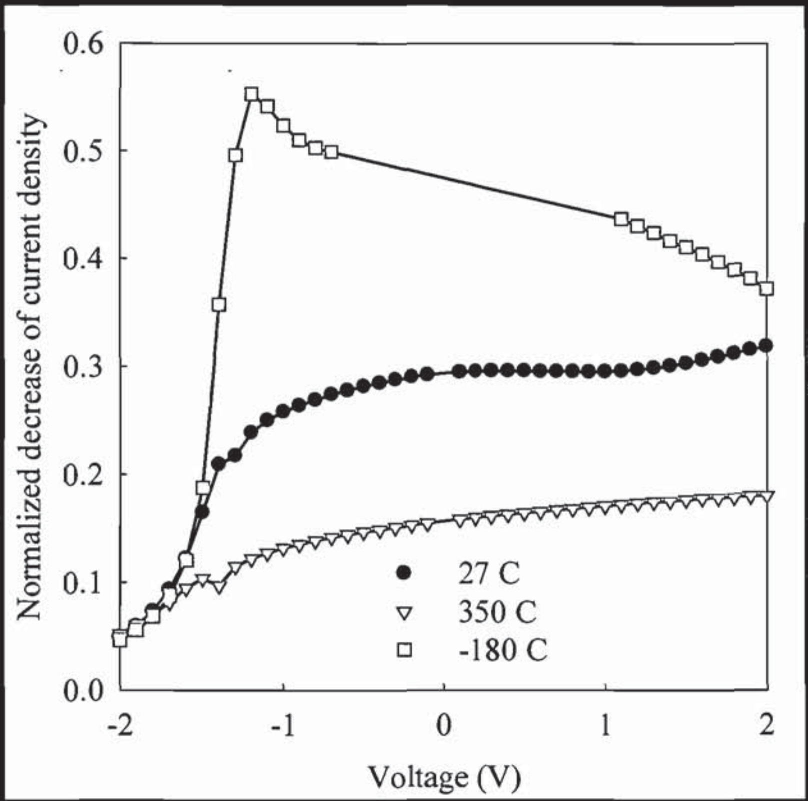
Modeling of Temperature Responses of n-I-n under High Pressure

Normalized change of current density under 10kbar for $GaN/Al_{0.15}Ga_{0.85}N/GaN$



Calculated with doping density of 3×10^{18} cm^{-3} for top GaN layer and 3×10^{17} cm^{-3} for bottom GaN layer. 10 nm thick undoped AlGaN layer is assumed.

- Current decreases with the applied pressure.
- The decrease gets more significant at lower temperatures.

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Pressure Responses of n-I-n Sensors

Sample Parameters		Maximum	Maximum
x	t_{AlGaN} [nm]	PGF [GPa^{-1}]	SGF
0.12	20	-0.492	386
0.15	20	-0.541	425
0.30	20	-1.02	807
0.15	10	-0.626	492
0.15	30	-0.3	236

pressure gauge factor (PGF): normalized current change per unit pressure

Higher gauge factor measured for nIn sensors with higher Al content in $Al_xGa_{1-x}N$

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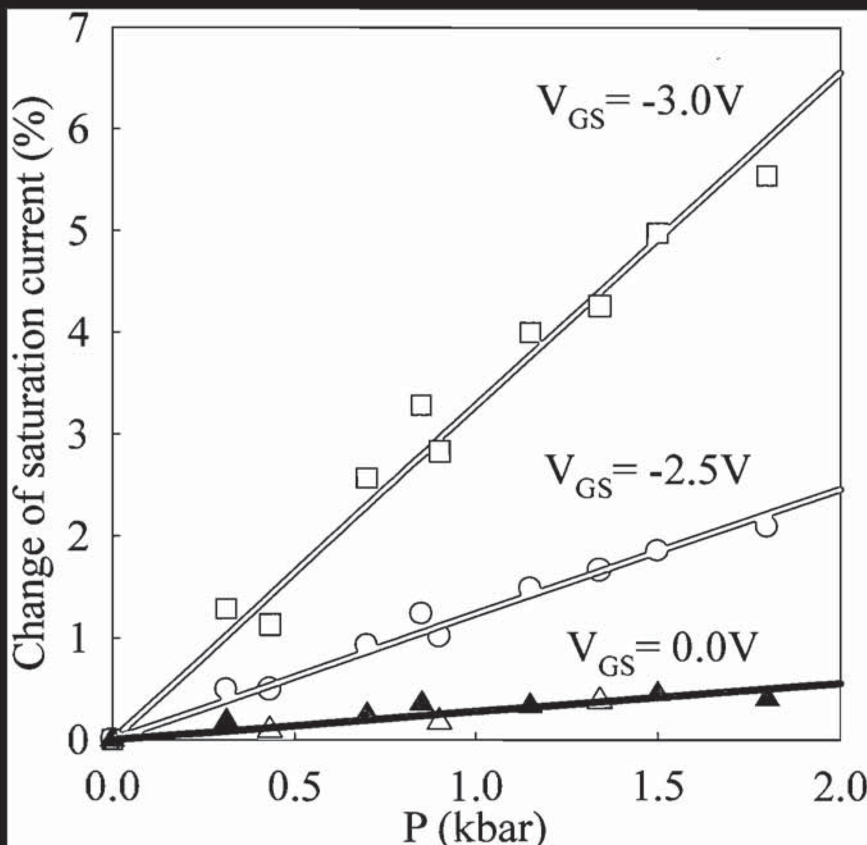
Pressure Responses of $Al_{0.3}Ga_{0.7}N/GaN$ HEMT Sensor

Relative change of saturation current with pressure



- Linear decrease of current with increasing pressure
- Reversible response

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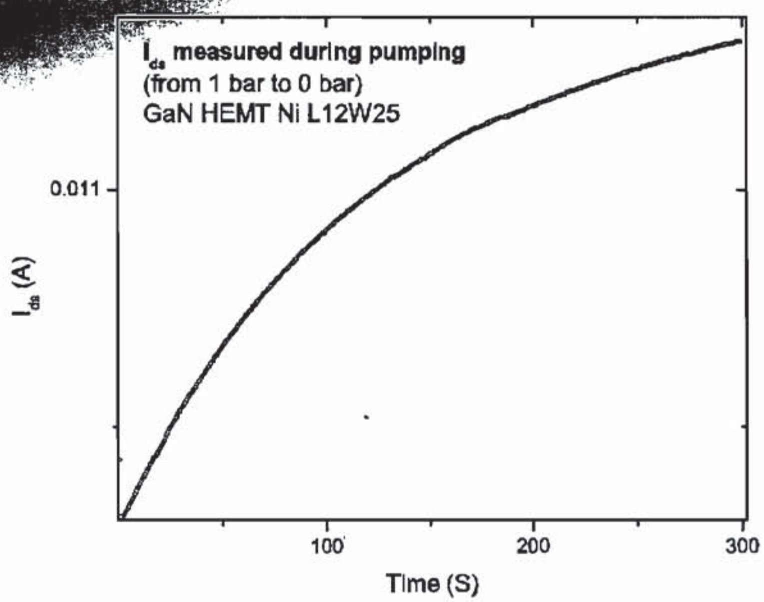
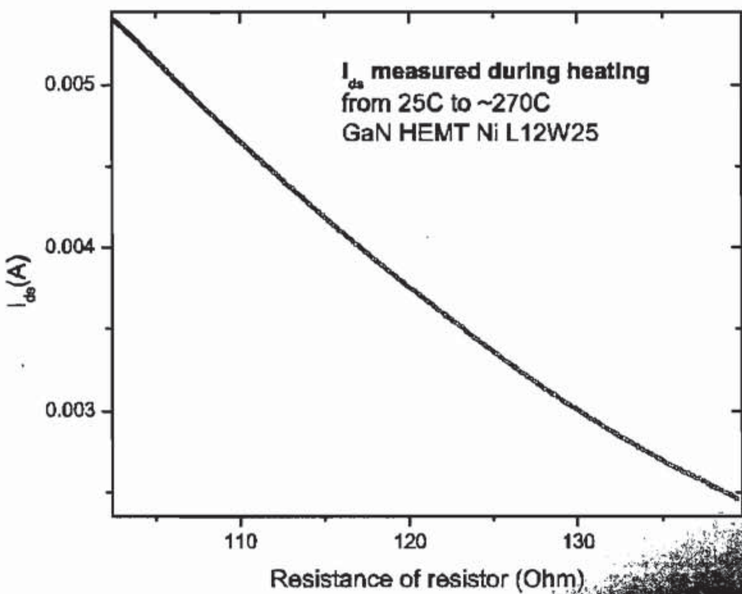
Pressure and Temperature Responses of $Al_{0.3}Ga_{0.7}N$/GaN HEMT Sensor





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Summary

- Investigated n-GaN/$Al_xGa_{1-x}N$/n-GaN (n-I-n) devices for pressure sensors in extreme environments.
- Theoretical modeling indicates decrease of electrical currents with increasing pressure due to the increase of polarization charge.
- The modeling predicts more significant decrease of current with higher AlN compositions in the $Al_xGa_{1-x}N$ layer and for the thicker $Al_xGa_{1-x}N$ layer.
- The vertical transport current measured with n-GaN/$Al_xGa_{1-x}N$/n-GaN (X=0.12, 0.15 & 0.2) sensors is consistent with the modeling studies.
- Linearity and reversibility in pressure response; n-GaN/$Al_xGa_{1-x}N$/n-GaN is promising for high-pressure sensing in extreme environments.

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