ABSTRACT

We report mesa-isolated Schottky barrier photodetectors fabricated on *n*-GaN. Single-element detectors were constructed from nitride epilayers grown by gas source molecular beam epitaxy (GSMBE) on Si(111). Chlorine-based reactive ion etching was used to form two-level mesas. The detectors were front-illuminated through 100 Å Pd semitransparent Schottky contacts on the upper mesas; ohmic contact on the lower mesas was made using standard Ti/Al/Ti/Au metallurgy. Silicon dioxide grown by plasma-enhanced chemical vapor deposition provided both surface passivation and electrical isolation. The dark current of an $86 \times 86\ \mu m^2$ single-element detector is 2.10×10^{-8} A/cm^2 at –2 V bias, and the zero-bias noise power density at 1Hz is as low as 9×10^{-29} A^2/Hz. Preliminary results for *p-n* diodes fabricated from epilayers grown on sapphire by GSMBE are also presented.

Low-noise, Low-dark-current GaN Diodes for UV Detectors

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ABSTRACT

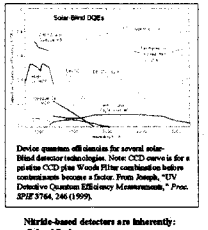
We report mesa-isolated Schottky barrier photodetectors fabricated on *n*-GaN. Single-element detectors were constructed from nitride epilayers grown by gas source molecular beam epitaxy on Si(111). Chlorine-based reactive ion etching was used to form two-level mesas. The detectors were front-illuminated through 100 Å Pd semitransparent Schottky contacts on the upper mesas; ohmic contact on the lower mesas was made using standard Ti/Al/Ti/Au metallurgy. Silicon dioxide grown by plasma-enhanced chemical vapor deposition provided both surface passivation and electrical isolation. The dark current of an 86 × 86 μm² single-element detector is 2.10 × 10⁻⁸ A/cm² at −2 V bias, and the zero-bias noise power density at 1Hz is as low as 9 × 10-29 A2/Hz. Preliminary results for *p-n* diodes fabricated from epilayers grown on sapphire by GSMBE are also presented.

UV SENSORS FOR SPACE ASTRONOMY HAVE REQUIREMENTS DISTINCT FROM THOSE FOR INDUSTRIAL OR MILITARY APPLICATIONS...

- Solar blind
- Low- noise readout techniques
- Low detector noise, since noise arising from the background often dominates in faint UV observations
- Low dark current
- Resistance to effects of operation in space

...AND SILICON EXHIBITS MANY BENEFITS AS A SUBSTRATE FOR GaN DETECTOR ARRAYS

- Large-area, low-cost, highly perfect substrates readily available
- Sophisticated backside process technology developed over many years
- Thermal expansion coefficient mismatch between detector arrays and readout electronics would be reduced



Device quantum efficiencies for several solar-blind detector technologies. Note: CCD curve is for a pristine CCD plus Woods Filter combination before contaminants become a factor. From Joseph, "UV Detective Quantum Efficiency Measurements," *Proc. SPIE* 3764, 246 (1999).

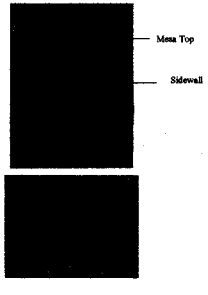
Nitride-based detectors are inherently:
- **Solar-blind**
- **Radiation-hard**
- **Chemically inert**
- **Operate at high temperature**

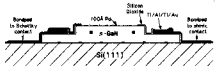
OUR PROCESS FLOW...

Epilayer growth	GaN grown by GSMBE on Si(111) and sapphire substrates
First etch	Chlorine-based reactive ion etching (RIE) Typically: 10sccm Cl_2 at 10mTorr and 200W rf
Isolation etch	
n-Ohmic metal	E-beam evaporated Ti/Al/Ti/Au, subsequently annealed in a N_2 ambient
p-Ohmic or Schottky metal	E-beam evaporated Ti/Pt/Au, subsequently annealed in a N_2 ambient, OR E-beam evaporated Pd
Passivation	SiO_2 grown by plasma-enhanced chemical vapor deposition (PECVD)
Interconnect	E-beam evaporated Ti/Au

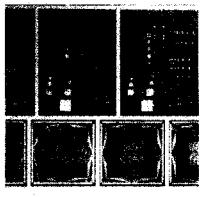
...INCORPORATES Cl_2 RIE WHICH RESULTS IN MESA STRUCTURES EXHIBITING:

- Anisotropic profiles
- Smooth sidewalls
- Smooth surface morphology
- Etch rates ~0.13μm/min.





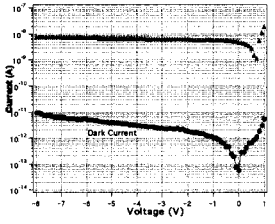
A SCHEMATIC CROSS SECTION OF THE DIODE STRUCTURE IS SHOWN ABOVE...



...AT RIGHT IS A DETAIL OF A FULLY PROCESSED WAFER INCORPORATING BOTH SINGLE-ELEMENT DETECTORS AND DETECTOR ARRAYS.

THE Pd/*n*-GaN/Si(111) SCHOTTKY DIODES EXHIBIT NOT ONLY LOWEST DARK CURRENT DENSITY FOR ANY GaN-BASED DIODE ON Si(111)...

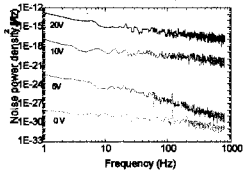
- *I-V* response of an 86×86 μm² single-element detector shown at right
- 100Å Pd Schottky metal on *n*-GaN
- Top curve shows I-V under UV illumination (Electro-Lite BOND Wand™ 81002 with emission between 320–380nm, peaked at 350nm and light output ~20mWcm⁻² at 350nm)
- Schottky barrier height determined from forward-bias I-V to be 0.9–1.1eV
- 2.10 ×10⁻⁸ A/cm² at -2V reverse-bias dark current density lowest for any GaN-based diode on Si(111)*



*Compare with 1.5 ×10⁻⁴ A/cm² reported earlier for similar detectors (A. Osinsky, S. Gangopadhyay, J.W. Yang, R. Gaska, D. Kuksenkov, H. Temkin, I.K. Shmagin, Y.C. Chang, J.F. Muth, and R.M. Kolbas, *Appl. Phys. Lett.* 72, 551 (1998).

...BUT ALSO THE LOWEST NOISE SPECTRAL DENSITY (NPD)

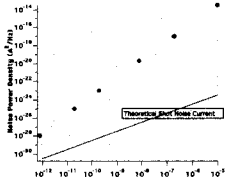
- 1/*f* noise is the dominant low-frequency contribution to the noise power density
- Zero-bias noise spectral density measured at 1Hz is 9 ×10⁻²⁹ A²/Hz
- Surface passivation provided by SiO_2 probably contributes to both low leakage and low NPD because of low interface trap density[5]



[5]see, e.g., H.C. Casey, Jr., G.O. Fountain, R.G. Alley, B.P. Keller, and S.P. DenBaars, Appl. Phys. Lett. 68, 1850 (1996).

NOISE POWER DENSITY VERSUS CURRENT SHOW DIODE IS NOT SHOT NOISE LIMITED

- Comparison of noise power density versus current with theoretical value of the shot noise, $I_{shot} = (2eI)$-, indicates diode is not shot noise limited
- Consistent with 1/f noise being dominant contribution to noise power density in this frequency regime
- GaN/Si(111) photodetectors have been shown* to be shot noise limited for the 0.1–2.2 MHz frequency range

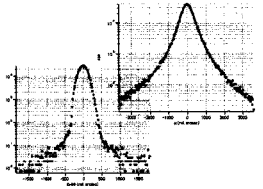


*A. Osinsky *et al.*, Applied Physics Letters 72, 551 (1998).

IN ADDITION TO *n*-GaN DIODES ON Si(111) FOR FRONT-ILLUMINATED DETECTORS, WE HAVE RECENT RESULTS ON *p-n* GaN DIODES ON Al_2O_3 FOR BACK-ILLUMINATED DETECTORS

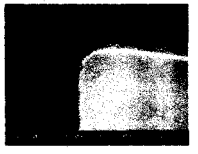
XRD SHOWS GOOD CRYSTAL QUALITY...

- ω-2Θ FWHM is 270 arcsec, ω FWHM is 580 arcsec (latter measurement taken with receiving slit in front of proportional counter removed
- Epilayer structure is 0.5μm GaN:Mg (2 × 10¹⁷ by *C-V*) on 1μm GaN on 0.4μm AlGaN



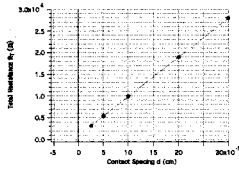
...BUT Cl_2 RIE OF THIS SRUCTURE CONTRASTS WITH RIE OF *n*-GaN/Si(111)...

- Both sidewall and surface morphology are rough
- Tencor Alphastep 500 measures 44 Å R_q over 500μm scan for unetched surface
- 106Å R_q over 500μm scan for unetched surface



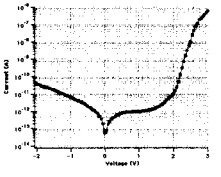
...AND *p*-METALLIZATION RESULTS IN HIGH CONTACT RESISTANCE

- Ti/Pt/Au, which has been shown to produce low-resistance contacts to *p*-GaN[§§]
- TLM measurements shown at right (measured data in red, fit to data in green)
- Specific contact resistance extracted from fit is 3.2 × 10⁻¹ Ωcm²



NEVERTHELESS, GaN/Al_2O_3 *p-n* DIODES EXHIBIT LOW DARK CURRENT DENSIT

- *I-V* response of a 50×50 μm² single-element detector shown at right
- Larger dark current density relative to Schottky diodes on Si(111) probably due in part to poor sidewall morphology



CONCLUSIONS

We have reported on mesa-isolated Schottky diodes fabricated from n-GaN epilayers grown by gas-source molecular beam epitaxy (GSMBE) on Si(111) that exhibit extremely low noise and dark current The dark current density and zero-bias noise spectral density of an 86×86 μm² single-element detector are, to our knowledge, the lowest values of these parameters reported for GaN diodes on silicon. We believe these results suggest that photodetectors based on GaN/Si(111) may possess many of the attributes required of space astronomy applications. In addition, we have presented preliminary results for *p-n* diodes fabricated from epilayers grown by GSMBE on sapphire.

ACKNOWLEDGEMENTS

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